Research article

Performance and mathematical self-concept in university students using Khan Academy☆

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ARTICLE INFO

ABSTRACT

Information and Communication Technologies (ICT) have fueled innovative support techniques in the educational field that enhance students' educational training processes. The goal of this study was to measure the relationships between progress in that training, mathematical self-concept, and the new students' academic performance when they were supported by an online training, through the Khan Academy platform. A sample of 906 students distributed over four cohorts was analyzed through correlational and inferential quantitative methodology. The results show that students' academic performance was directly related to their mathematical self-concept, their progress in the online training, and other socioeconomic factors, such as being in receipt of grants, their parents' educational attainment, and access to technological devices at home, highlighting a technological gap in academic performance in favor of students with access to such devices. Further research is needed about the role of teachers and the methodology that accompanies learning through this technological tool.

1. Introduction

Over recent years, higher education has undergone various changes, not only in how the institutions are organized, but also in the quality they must offer their students and future graduate professionals [1]. Currently, at an international level, there is a downside which is common to all mathematics-related subjects taught in Higher Education Institutions (HEIs), students either abandoning or missing out a subject [2,3]. This is one of the main causes of university dropout [4]. The World Bank indicated that over time in Colombia, the context of this study, the percentage of university dropout was over 40%, one of the highest rates in Latin America [5]. The impact of dropout is clear in the first few weeks of higher education, due to new students' poor performance in the basic sciences, and there is a special training gap in prior mathematical knowledge [6,7].

That impact is deepened when the HEIs have a strong social component in the student selection process, and they do not have requirement for an admission test or a minimum score in state testing. Based on this, some of these HEIs implemented different programs for modifications of the mathematics curriculum or implementations of tutorships or counseling. One of these tools consists of giving the students the possibility of a more autonomous learning via incorporating ICT (Information and Communication Technologies) offering freshmen the opportunity to fill in the gaps in their education with online training based on open access technologies such as Geogebra, Symbolab, MOOCs, Moodle, Kahoot, or Khan Academy, among others.

☆ Advances in smart classrooms for shaping learning spaces

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The present research focuses on the effects of an online training on performance and mathematical self-concept of new students enrolled at one HEI, which was designed and implemented mediated by the Khan Academy platform, with the aim of bringing new students' prior math knowledge gaps [8]. The training covered 8 topic units and 104 skills distributed as follows: Fundamentals (31 skills), Algebraic expressions (10 skills), Expressions with exponents (11 skills), Quadratics and polynomials (12 skills), Linear equations and inequalities (14 skills), 2×2 Equation systems (7 skills), Geometry and equations (6 skills), and Line and Slope charts (12 skills). Based on Khan Academy's facilities, students had access to videos, interactive exercises, and instant feedback that allowed them to reinforce their prior learning in mathematics individually and at their own pace. A previous study [8] found the effectiveness of this online training in terms of mathematical learning, with the active support of teachers. With the present study, the aim was to go further, identifying the various factors that could affect academic performance, opting for a social, technological, and personal perspective to examine the students' perceptions of their mathematical skills.

Because previous studies have shown that mathematical self-concept is one of the variables that most impacts academic performance [9,10], the objective of this study was to measure the relationships between mathematical self-concept, progress in the online training, and academic performance in mathematics in new university students. The following research questions were formulated:

- Q1: Is there an association between mathematical self-concept and academic performance in mathematics subjects?
- Q2: Is progress in the online training related to academic performance in mathematics subjects?
- Q3: How is progress in the online training and mathematical self-concept related?
- Q4: Are socio-technological factors as students' grant coverage, parents' educational attainment, number of electronical devices or socioeconomic levels related to mathematics academic performance and mathematical self-concept related?

1.1. Theoretical background

Self-concept is defined as an individual's perceptions of themselves, formed from cognitive factors and influenced by the reinforcement of the surroundings and the evaluations of others [11,12]. Educational research has included self-concept as an object of study [13,14]. The results of various studies have confirmed a strong relationship between academic self-concept and some educational variables such as academic performance [15,16] and difficulties with learning [17]. They have also shown the predictive power of self-concept on student academic performance [9]. However, fewer studies have focused on increasing the levels of academic self-concept [18].

Mathematical self-concept lies within self-concept and refers to a person's perceptions of their own mathematical abilities [19]. Mathematical self-concept plays a fundamental role in the learning process, as well as in students' aspirations for the future [20]. Various studies [21,22] have shown mathematical self-concept to be positively related to academic performance. They have also indicated a gender gap in favor of men, and a development gap suggesting that mathematics and scientific self-concept diminish as students get older. In addition, [10] showed reciprocity between mathematical self-concept and mathematics anxiety, in other words, greater self-concept led to lower anxiety, which in turn led to greater self-concept.

For many years, teachers have guided the learning process with few tools such as blackboard and chalk, trying to ensure that all their students learn the same things at the same pace, with the risk of boring the more advanced students or leaving the lagging students behind [23]. The use of digital tools in education is gaining ground every day because it adds dynamism to the teaching-learning process, particularly in mathematics [24,25]. Implementing ICT encourages autonomous, reflective learning in the process of teaching mathematics skills which in turn strengthens students' self-concept, promoting the construction of specific and general skills for future professionals [26–28].

Out of the Open Educational Resources (OER), the Khan Academy technological platform offers individualized learning that allows students to progress at their own pace in activities that are accompanied by videos, interactive theory summaries, practical problems, and video-game-like rewards and badges for progress [29,30]. In addition, the website offers software that gives instant feedback for answers and the step-by-step solution of each exercise [31]. Khan Academy has a learning system based on artificial intelligence that can identify learners' strengths and weaknesses through mastery challenges, allowing the overall challenge of a course, or the levels of the different skills, to be increased or decreased [32]. Once the students correctly answer all the questions, the platform automatically suggests new topics based on the prior knowledge mastered to that point, allowing self-regulation of learning [33].

The Khan Academy approach shows that learning progression can be personalized, and that each student can receive individualized help when they need it [24]. Nonetheless, critics argue that the Khan Academy videos and software encourage mechanistic learning that has little creativity and lacks the interaction that would come with real teachers [34]. Whatever the limits of the platform may be, it has been extremely popular. More than 2 million users watch videos each month and around 15 questions are answered every second. It is a fact that Khan Academy is being used as an OER by many students, and if they do that, it is because it helps them to pass difficult subjects (a separate issue, not addressed by the current study, is whether the evaluation methods in these subjects in higher education encourage passing via mechanistic learning or not). In particular, Khan Academy has led to more students all over the world being more self-confident about their mastery of mathematics skills [35]. The study by [8] showed, with a different sample in the same HEI, that online training significantly improved academic performance for students who followed it compared to those who did not, and that the more progress the students made in the online training, the better the academic performance.

2. Materials and method

A quasi-experimental design was conducted to answer the research questions, by using descriptive and post-hoc inferential statistical analyses.

2.1. Population and sample

The reference population for this study was the 14,673 new students in the academic programs in the Natural Sciences and Engineering, and Socioeconomic and Business Sciences faculties in a HEI in Colombia, between the second semester of 2018 and the first semester of 2020. All of them were invited to do the online training in the admission stage before they enrolled, leading to 6,371 signing up. A total of 1,474 students were discarded from the study for not progressing through at least 10% of the tasks on the online training, as they were considered to have had no or very little participation in training. Subsequently, out of the remaining 4,879, we considered students for whom there was information about their academic performance and mathematical self-concept. This resulted in a final sample of N = 906 students.

Ethical approval for this study was obtained from the *Comité de Ética para la Investigación, Bioética e Integridad Científica – Unidades Tecnológicas de Santander* (Ethics Committee for Research, Bioethics, and Scientific Integrity), and informed consent was obtained from all participants prior to their inclusion in the experiments.

2.2. Data collection and analysis

Data collection was through information produced by the Khan Academy platform (progress in the online training from the second semester 2018 to the first semester 2020), the databases of academic performance in the mathematics subjects managed by the HEI internal platform, and an online questionnaire. The main aim of the questionnaire was to collect general information about social backgrounds, access and use of technological media, and students' perceptions about their mathematics skills. The questionnaire had three parts: 1) four questions about general data: ID numbers, socioeconomic level, parents educational attainment, and whether the participant was receiving a grant; 2) six questions about exposure to and use of technological devices at home, home internet connection speeds, and parents' use of the internet; 3) six questions assessing the students' mathematical self-concept, based on the questions in the 2019 student TIMSS (Trends in International Mathematics and Science Study) questionnaire related to enjoyment of learning mathematics, students' confidence in mathematics, and clarity of teaching [36]. Each item about mathematical self-concept used a Likert-type scale with 5 response options from (1) Completely disagree to (5) Completely agree. The questionnaire was designed on Google Forms® and was applied to the study sample and administered via email during the 2018, 2019, and 2020 semesters.

Data analysis was performed using RStudio (version February 1, 5025). The first step was a descriptive analysis of the questionnaire data and the calculation of the Cronbach reliability coefficient for the items related to mathematical self-concept, which was 0.712. The analyses performed by the TIMSS study also support the validity of these items. During the administration of the questionnaire there were no issues or problems relating to item comprehension or the content of the questionnaire. A quantitative scale was used to assess progress in the online training, from 10 to 100% split into four segments: low [10 to 30%], basic [31 to 59%], outstanding [60 to 79%], and excellent [80 to 100%]. This scale was chosen following the results of the study by [37] which showed that students who completed 60% or more of the mathematics courses in Khan Academy corresponding to their level of schooling had 1.8 times better expected results in mathematics regarding the external MAPGrowth standardized test. Academic performance was measured using the Colombian grading scale, from 0 to 5 points, with a pass mark of 3. Secondly, given the sample size and the type of variables, the Shapiro-Wilks normality test was performed, the result of which showed that none of the study variables could be said to have a normal distribution. Therefore, the Kruskal-Wallis (KW), Nemenyi (N), and Mann Whitney (MW) tests were used to perform non-parametric inferential analysis.

3. Results

3.1. Participants' socio-technological profiles

The socioeconomic strata in Colombia are classified from 1 to 6, from the lower to the upper levels.[1] The results of the study indicate that 86.76% of the students belong to the lowest socioeconomic levels (46.14% from level 1 and 40.62% in level 2), whereas 10.71% belong to level 3 and only 2.54% belong to the upper socioeconomic levels (2.43% from level 4, none from level 5 and 0.11% from level 6, i.e., only one student). The distribution of the socioeconomic status is obviously reflected in the technology available at home. Fig. 1 shows the distribution of the number of devices available at home depending on the socioeconomic level (strata 5 and 6 were omitted from the graphic to gain clarity and due to their lack of representativeness).

More than half (59.59%) of the students received full grants for their educational costs. Most (83.22%) students reported basic or moderate educational attainment for their parents and 40.84% reported that their parents never or almost never used the internet. Over two-thirds of students reported basic and intermediate use of the internet, and home connection speeds were generally between

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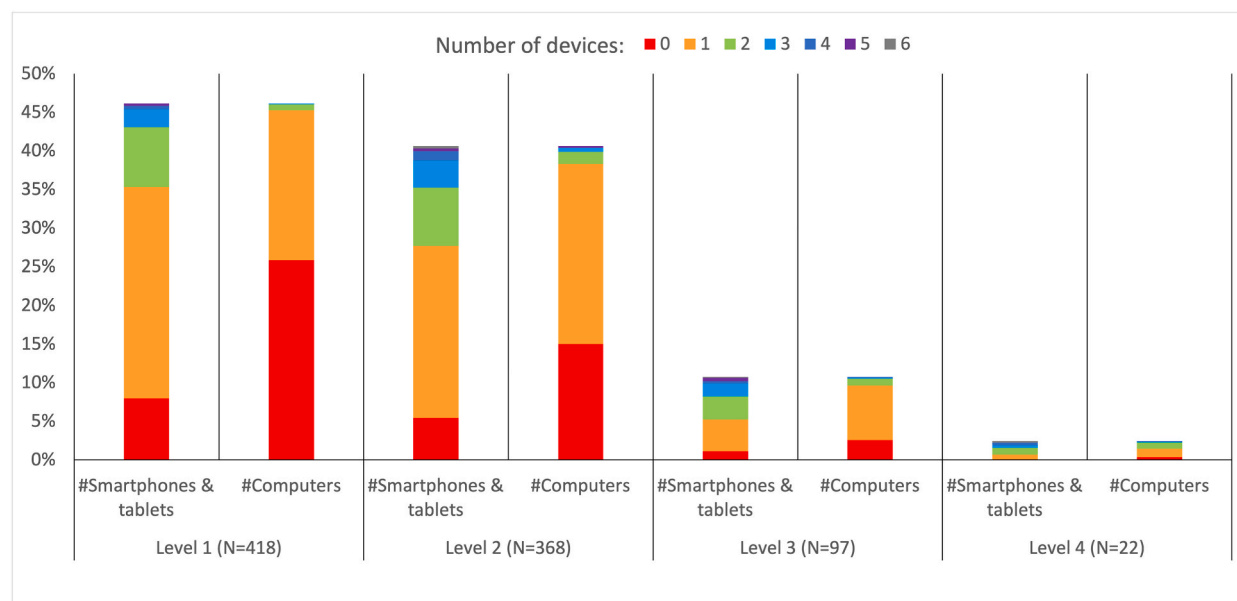
Fig. 1. Technology available at home (number of devices) depending on the socioeconomic level (color scale). Own elaboration. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

one and five megabytes (61.26%), although 8.9% said they had no internet services at home.

3.2. Mathematical self-concept

Fig. 2 shows that 54% of the students either completely disagreed, disagreed, or neither agreed nor disagreed with the statement 'I think I am capable and skillful at mathematics'. In addition, 42% agreed or completely agreed with the statement, 'Being a good mathematics student makes me feel that my classmates and teachers think more of me'. More than half (57%) agreed or completely agreed with the statement, 'My performance in mathematics largely depends on the methodology and empathy with teachers'. The data also indicate that 25% of the students agreed or completely agreed with the item, 'In the mathematics exams I feel unsure, desperate, and nervous.'

Fig. 3 shows that 77% of the students agreed or completely agreed with the item, 'Mathematics is useful and necessary in all areas of life', while 59% of the participants agreed or completely agreed with the statement, 'The online training allowed me to reinforce the prior mathematics knowledge needed for the learning in my course'.

3.3. Academic performance

The average grades for academic performance in mathematics subjects were above the pass mark of 3 in all the semesters, trending upwards over time (3.34 in the second semester of 2018, 3.53 in the first semester of 2019, 3.64 in the second semester of 2019, and 4.3 in the first semester of 2020).

Fig. 4 shows the percentage of participants in each section of the scale of progression through the online training. The data show a notable improvement between the first and second implementations. The percentage of students with low progression was 46.6% in the first implementation, falling to 23.9% in the second. The proportion of students whose progression was outstanding and excellent increased in the first and second semesters of 2019, and although it fell slightly in the first semester of 2020, it was still an improvement on the results of the first implementation in 2018.

3.4. Relationships between variables

The results of the MW tests at the 5% level of significance showed that academic achievement differed significantly between the two progression groups. The students who progressed through 60% or more of the online training had better academic performance than students who progressed through less than 60%. The results of the KW test at the 5% level of significance showed statistically significant differences between the students' academic performance and their mathematical self-concept (see Table 1).

The mean and median scores of the response groups to the item, 'I think I am capable and skillful at mathematics', exhibited a positive relationship, students who gave higher scores to their mathematical self-concept in relation to this item had better academic performance (see Table 1). Similarly, the response groups to the variable, 'Being a good mathematics student makes me feel that my classmates and teachers think more of me', demonstrated statistically significant differences in students' academic performance.
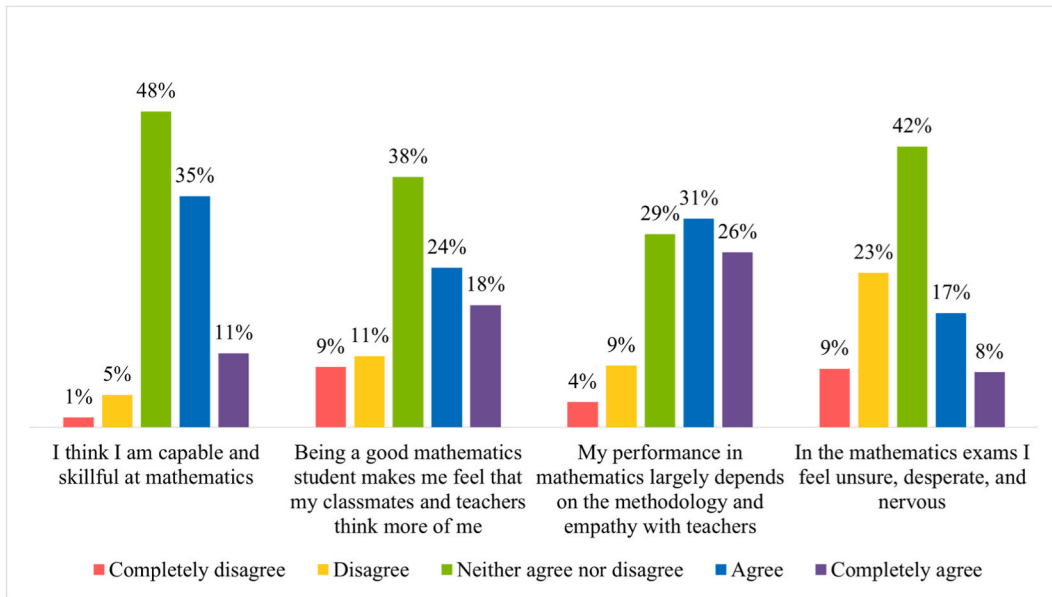
Fig. 2. Participants' responses about mathematical self-concept. Own elaboration.
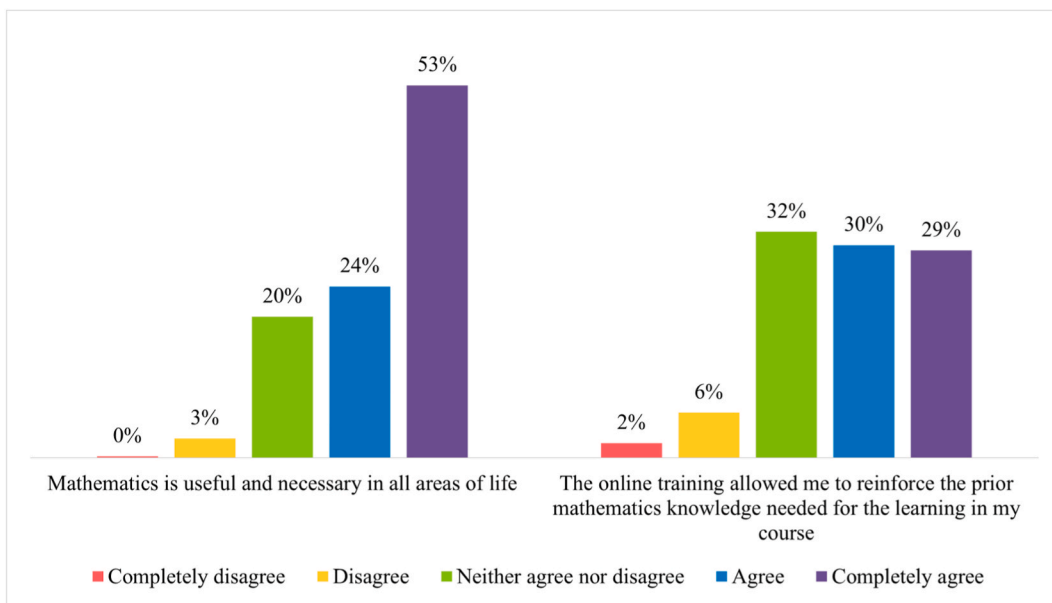

Fig. 3. Students' perceptions about mathematics and the online training. Own elaboration.

Students who felt that performing well in mathematics made them feel more highly valued in the classroom had better academic results (see Table 1).

Significant differences were also found between the academic performance of students who rated their mathematical self-concept as low via the item, 'In the mathematics exams I feel unsure, desperate, and nervous', and those who scored their self-concept highly via this item, with the latter performing better. The means and medians of the different response groups exhibited a negative relationship, less anxiety was associated with greater levels of academic performance (see Table 1).

Similarly, the relationship between academic achievement and agreement with the statement, 'Mathematics is useful and necessary in all areas of life', demonstrated that the academic performance of students who scored this item higher (5 = completely agree) was significantly different from the performance of the other response groups. The mean and median scores of the different groups exhibited a positive relationship, higher scores in the perception of mathematics were associated with higher levels of academic performance (see Table 2).
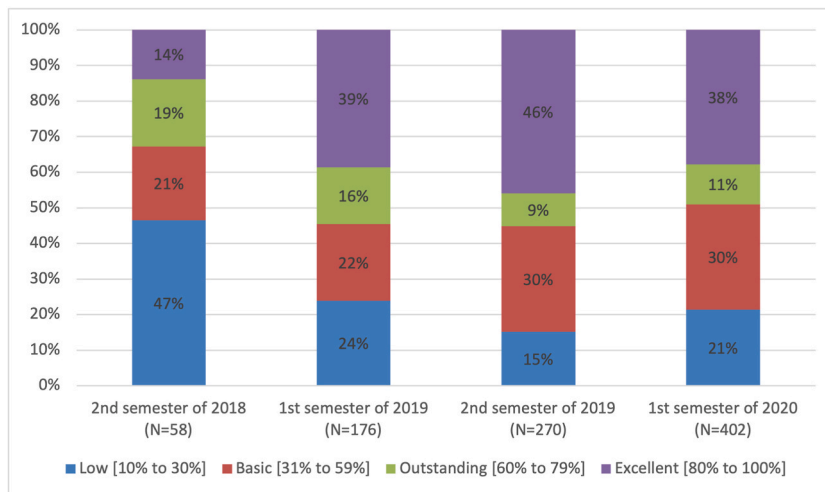
Fig. 4. Development of percentages of students in each part of the scale showing percentage progression in the online training. Own elaboration.

Table 1
Nemenyi post-hoc tests for academic performance and mathematical self-concept (α = .05). Own elaboration.

Item	Scale	Mean academic performance	Median academic performance
I think I am capable and skillful at mathematics	1	3.24 a	3.23 a
	2	3.47 a	3.35 a
	3	3.75 a	3.80 a
	4	4.09 b	4.24 b
	5	4.15 c	4.50 c
Being a good mathematics student makes me feel that my classmates and teachers think more of me	1	3.91 d	4.00 d
	2	3.79 de	3.90 de
	3	3.82 df	3.90 df
	4	3.94 dg	4.10 g
	5	4.03 g	4.30 g
In the mathematics exams I feel unsure, desperate, and nervous	1	4.08 h	4.50 h
	2	4.03 hi	4.20 hi
	3	3.86 j	3.90 j
	4	3.85 ik	3.90 ik
	5	3.59 l	3.60 l

Note: different letters represent significant differences.

Table 2
Nemenyi post-hoc tests for academic performance and utility of mathematics (α = .05). Own elaboration.

Item	Scale	Mean academic performance	Median academic performance
Mathematics is useful and necessary in all areas of life	1	3.40 a	3.40 a
	2	3.51 a	3.60 a
	3	3.80 a	3.80 a
	4	3.83 a	3.90 a
	5	3.98 b	4.17 b

Note: different letters represent significant differences.

Table 3
Nemenyi post-hoc tests for academic performance and grant holding (α = .05). Own elaboration.

Item	Scale	Mean academic performance	Median academic performance
Grant	No	3.78 a	3.90 a
	Yes, the grant covers 50% of the costs of study	3.87 ab	4.00 ab
	Yes, the grant covers 100% of the costs of study	3.96 b	4.10 b

Note: different letters represent significant differences.

There were also statistically significant differences between academic performance and some of the socio-technological variables examined. The KW test showed that the academic performance of students who were not receiving a grant differed from the performance of those students whose grants covered 100% of the costs of their study. The mean and median scores of the groups exhibited a positive relationship, students who received financial assistance that paid for their study had higher levels of academic performance than the less fortunate who were not receiving any grants (see Table 3).

The MW test indicated that academic performance also differed between the response groups in relation to parents' educational attainment (p-value = .0075). Higher levels of attainment from the parents were associated with increased academic performance in mathematics from their children. In terms of technology, performance also differed between the groups with regard to the number of smartphones or tablets (p-value = .0034 in MW test): students who had access to more devices at home (between 4 and 6) had better academic performance than students who had access to fewer devices (between 0 and 3). Finally, the data showed that the academic performance of students who did not have computers at home was worse than the students who had one or more computers at home (p-value = .0035 in MW test). Table 4 shows the median academic performance for the different groups.

The MW test indicated (p-value = .0218) that the percentage of progression through the online training differed significantly when considering the responses to the item, 'Being a good mathematics student makes me feel that my classmates and teachers think more of me'. Students who did at least 80% of the online training felt that performing well in mathematics made them feel that they were more highly valued in class. The MW test showed (p-value = .0006) that students who scored the item 'Being a good mathematics student makes me feel that my classmates and teachers think more of me' higher exhibited a statistically significant difference in the percentage of the online training they completed. Not only did doing more of the training mean better self-concept, but better self-concept also meant doing more of the training.

In addition, the KW test showed (p-value = .0171) that the students from socioeconomic levels 1, 2, and 3 felt less capable in terms of mathematics skills compared to students from higher socioeconomic levels, who always or almost always felt secure in their mathematics skills. Furthermore, students who had access to smartphones and tablets at home felt more capable in mathematics compared to those who had no access to these devices at home (p-value = .0012 in KW test).

Finally, the Kruskal-Wallis (KW), Nemenyi (N) and Mann Whitney (MW) tests did not reflect any other statistically significant differences between the response groups analyzed for each of the study variables in terms of academic performance and mathematical self-concept (with p-values over .5). In particular, no differences were found between academic performance and socioeconomic level.

4. Discussion

The socioeconomic data offer a clear x-ray of the student profile in this HEI, mostly from low socioeconomic levels and families with low educational attainment, dependent on grants and subsidies to stay in higher education. These are all factors that the literature has indicated as encouraging academic dropout [4,38]. If we also consider the scant technological resources available to these students and their limited access to the internet, mostly through smartphones, we gain a clear picture of the difficulty of the context.

Nonetheless, despite the various difficulties faced by students, there was a progressive improvement in academic performance over time, associated with a variety of factors, particularly the online training. Although the training is not the only factor having an effect, our study confirmed improvements in academic performance that were parallel to the increase in the number of students who used it and the increase in progression through the online training.

With regard to the first research question, the results of the study confirmed the direct relationship between students' mathematical self-concept and their academic performance [22,39]. However, no relationship was found between academic performance and the statement, "My performance in mathematics largely depends on the methodology and empathy with teachers", despite the literature indicating that teachers are one of the variables that have the most impact on student academic performance [9]. This discrepancy may be because studies which have argued for a direct relationship between these variables have focused on observation of teaching methodology in the classroom and not on student perceptions. It may also be since one of the conditions of receiving a grant is to meet minimum performance levels to continue receiving it, although [6] reported that the numbers of students dropping out in the first semester were unrelated to being in receipt of a grant.

In terms of the second research question, the data confirmed that students who advanced through at least 60% of the online training performed significantly better than those who did less of it, which is consistent with [37]. It should also be noted that this result held even when the online training was independent of the methodologies different teachers used in their teaching-learning processes in mathematics subjects. This is because the training was implemented by a group of teachers outside the classes, who were asked to report the students' progress monthly to their teachers and who were responsible for all the technical aspects of how the training

Table 4
Median academic performance depending on some items. Own elaboration.

Item	Scale	Median academic performance
Parents' educational level	Basic and medium	4.00
	Superior and University	4.20
# Smartphones or tablets	[0–3]	4.00
	[4–6]	4.30
# Computers	0	4.00
	[1–6]	4.31

worked. The online training working group's activities included training teachers in the use and implementation of Khan Academy in the classroom, however the main problem they had was that from one semester to another there were drastic changes in teachers assigned to first-semester mathematics courses.

With regard to the third research question, the results of the study contribute to the little research there has been about factors which encourage improved mathematical self-concept. The study shows that there is a reciprocal relationship between the online training and, 'Being a good mathematics student makes me feel that my classmates and teachers think more of me'. As students manage to progress through 80% or more of the online training, they feel more certain that they are good mathematics students, and thus feel more highly valued by their classmates and teachers. This feeling of recognition is important for strengthening students' mathematical self-concept, which is in turn reflected in their academic performance [22]. For students, status is important, and the appreciation of their classmates and teachers when they perform well in mathematics and strengthen their learning in a more autonomous setting makes them feel like better mathematics students, which is reflected in better academic performance. In contrast to the study from [35], in this study, no evidence was found that progression in autonomous work through the online training via Khan Academy contributed to reducing levels of stress or nervousness when it comes to doing mathematics exams.

In response to the fourth research question, other factors were found that influenced academic performance, although we did not establish significant influence of factors that the literature has linked to performance, such as socioeconomic level [40]. This discrepancy may be related to the compensating effect of grants, given that a large proportion of this HEI students receive financial support [41]. Despite the lack of an explicit relationship, socioeconomic level implicitly affected academic performance, as it appeared to be related to other relevant factors. We found a relationship between socioeconomic level and access to technological devices such as smartphones and tablets, which highlights the importance of having a favorable socioeconomic setting and sufficient access to technology to ensure student learning [42]. Students from the lowest socioeconomic levels felt less capable in mathematics than students from higher levels, and this influenced the academic performance of these new students in mathematics [43]. The level of internet use and the speed of connections that students had at home was not a limitation to academic performance, but having various technological devices available was, highlighting the technology gap in academic performance in favor of students who have access to such devices [44,45]. However, despite its technological nature, we did not find significant differences in progression through the online training and the socio-technological variables in the study.

5. Conclusions

The main conclusion of this research is that using Khan Academy resources makes it possible to broaden the retention opportunities for less-advantaged students and contributes to facilitating their access to information, adapting to the diverse educational, personal, family, and social needs of those HEI students. More specifically, using a learning methodology enriched with videos, interactive materials, and instant feedback encourages students' autonomous learning and enhances their mathematical self-concept [46], it facilitates their access, although one must bear in mind that the results indicate most students connect via smartphones which makes it harder to read or write documents, while making it easier to access video and audiovisual resources.

The study demonstrates a direct relationship between mathematical self-concept and the academic performance of new students who use technological tools such as Khan Academy. Using these kinds of tools encourages students' autonomous learning using videos and interactive practice that they can access at any time through various technological means. This makes it easier for them to balance their day-to-day tasks with their academic activity and contributes to reducing the technological and educational gap between life inside and outside the classroom [47].

The results of this study provide important information for educators and those responsible for formulating education policy, especially in similar social or geographical environments, regarding the construction of classroom environments and the design of curricula and online reinforcement strategies that promote autonomous learning via ICT. The goal is to enhance mathematical self-concept and make students' education more dynamic, strengthening academic support and hence reducing the marked academic inequalities in public HEIs, such as the one considered here, highlighting its important role in a society such as that in Colombia.

Among the limitations of the study, it is worth noting that despite the large sample size, it was not a census study, and the sample selection was not random but was affected by the student information available. This may hide important information from those who did not respond to the mathematical self-concept questionnaire, although the results about the relationship between performance and the online training were from the full cohort in [8], and the difference in terms of average performance is less than .4 points in the score (statistically significant), favorable to those in the subsample considered here. Additionally, since it was not a randomized controlled trial, results, even when being relevant, cannot be generalized to all the Colombian university population.

Finally, the main future lines of research that these results may lead to are related to increasing mathematical self-concept through autonomous learning and its articulation with Khan Academy, along with an examination of the role and attitudes of teachers towards an external online support tool for their students.

Production notes

Author contribution statement

Karol Lisette Rueda-Gómez: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Luis J. Rodríguez-Muñiz, Ph D; Laura Muñiz-Rodríguez, Ph D: Conceived and designed the experiments; Analyzed and interpreted

the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

The data that has been used is confidential.

Declaration of interest's statement

The authors declare no competing interests.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e15441.

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