Unlocking Equality and Sustainability in Scientific Vocations [1]

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ABSTRACT

This study provides evidence of how System Dynamics and Group Modeling can be used to understand the complex factors that hold back progress in scientific vocations in the Colombian Department of Santander. This study examines the issues of inequity and economic sustainability risks in a scientific vocation system. Through a combination of group modeling, system dynamics, inequity, and overshoot-and-collapse archetypes, we were able to identify and analyze the underlying dynamics that drive scientific vocation in the Department of Santander. As a result, we propose potential strategies to counteract these risks and increase economic growth in rural areas. This research highlights the importance of equitably organizing the scientific vocation process to create competitive advantages and secure long-term economic development in the Department of Santander.

KEYWORDS:
System Dynamics Group Modeling, student motivation, engagement, personal relevance, action plan, scientific vocation, rural development, resources, effective development

INTRODUCTION

The development of scientific vocations is essential to advancing rural regions in Colombia and the Department of Santander and requires effective strategies to motivate and engage students. However, inequality and low growth remain issues in scientific research. Therefore,

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[1] The results presented in this paper are derived from the social intervention and research project entitled "Strengthening Scientific Vocations for Rural Development in the Department of Santander," with the SIGP COD. 72457 and BPIN 2020000100025. Our study was funded by the Ministry of Science in Colombia and a consortium of universities, including the Universidad Autónoma de Bucaramanga, Universidad de Santander, and UniSangil. We are grateful to Policy Dynamics for their collaboration and support. Through the project's development, which focuses on strengthening scientific vocations for rural development in the department of Santander, 120 research projects developed by children and adolescents belonging to elementary and middle school educational institutions will be supported, affecting 30 municipalities and 120 teachers. Likewise, the project proposes the development of 11 spaces for scientific dissemination in Santander and contemplates an impact evaluation that will allow the identification of its influence on the participants during the execution of the project over 24 months.

investing in scientific vocations is critical for creating a promising future for Colombia’s rural areas and the Department of Santander. Research is needed to determine the best ways to spark student interest and performance.

Several studies have shown strategies to motivate the younger population to connect science courses with their daily lives to promote student interest and performance (Hulleman & Harackiewicz, 2009). Educators and funding agencies promote the relevance of education for students to increase their engagement and learning (Newby, 1991). When science courses are personally meaningful and relevant, students can become engaged in the learning process, focus their skills on science careers, become involved in science activities, and think about entering college to pursue a career in science (Hulleman & Harackiewicz, 2009).

When we conducted a literature review using the keyword 'scientific vocations, we initially found that the topic gained relevance over the years, as indicated by the increasing number of citations per year.

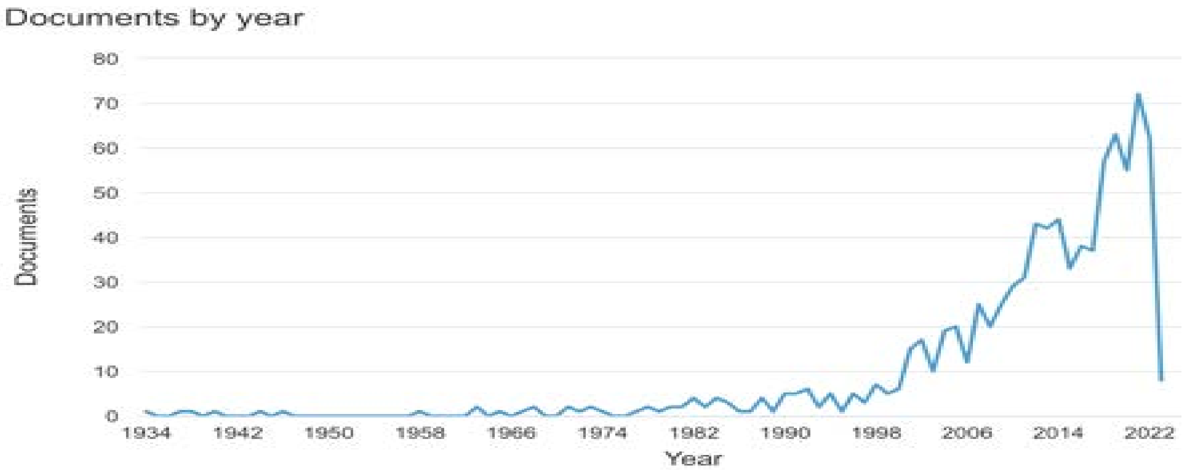

FIGURE 1. An increase in interest in scientific vocations was derived from the number of documents published with these keywords between 1934 and 2023.

The chart below was taken from a search of the Scopus database on March 17, 2023, using the keywords "science" and "vocations. " The graph reveals the prevalence of nodes related to issues of gender in scientific vocations, training of vocations, and the supply problem of vocations. However, topics such as the sustainability of scientific vocations, the use of system dynamics, and group modeling to study sustainability and equity in scientific vocations are not evident.

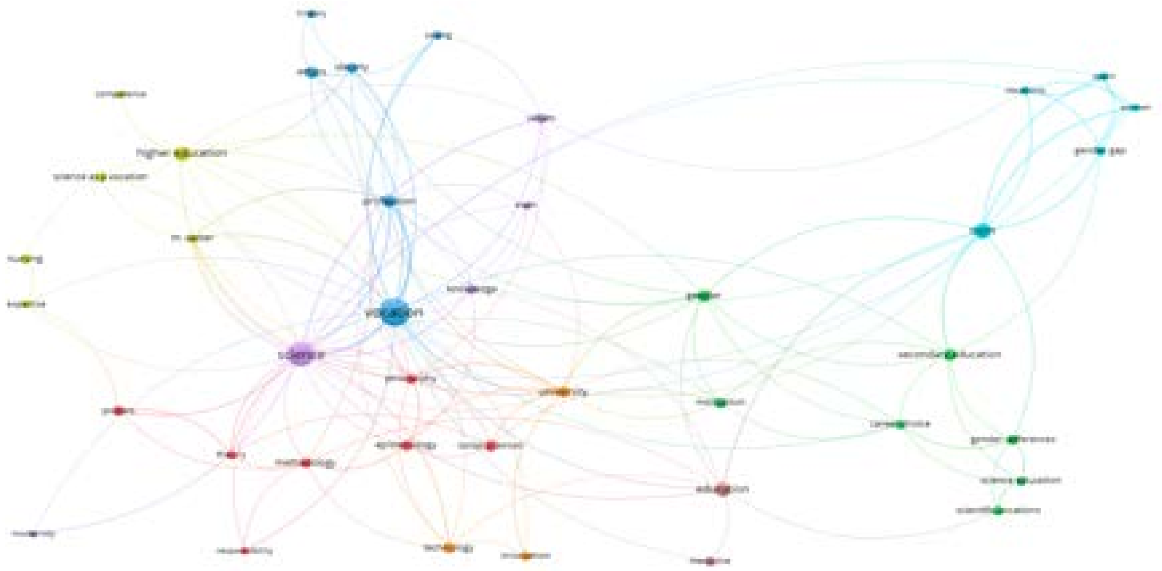

FIGURE 2. Scientific Map using science and vocations as keywords

Through the study of scientific literature, various types of experiential learning, gaming, and virtual reality that could be used to engage students in scientific vocations can be identified. As a result, researchers can identify how to create an environment in which both men and women feel motivated and interested in learning, such that a more equitable outflow of students in science-related fields is achieved. Furthermore, a scientometric analysis can reveal how the perceptions of gender and culture influence the interest in pursuing a scientific vocation and provide a greater understanding of the areas in which additional research, educational interventions, or policy-making are needed to reduce gender-based disparities in these vocations.

We ask the literature: How does the concentration of scientific vocations in rural areas compare to that in urban areas? Research has suggested disparities between rural and urban areas in terms of resources, opportunities, attitudes, academic performance, and occupations (Mupezeni, 2018; Astalini, 2020; Kryst, 2015; Alasia, 2005). Mupezeni (2018) found that rural learners' activities were impacted by inadequate school facilities, and lack of support, mentorship, and equipment. Astalini (2020) determined that there are significant differences in the attitudes of students in rural and urban areas. Kryst (2015) reported that students attending rural schools had significantly lower science scores, and the rural disadvantage was observed to increase between 1995 and 2011 in some countries, though not in others. Alasia (2005) found that managerial and professional occupations were concentrated more in predominantly urban regions than in rural regions, whereas the intensity of unskilled occupations was more prominent in rural regions. These differences may influence the concentration of scientific vocations in rural areas compared with urban areas.

We then ask the literature: What can be done to make science vocations more sustainable? One way to make science vocations more sustainable is to change the teaching methodology and introduce current and relevant scientific topics (Dopico, 2017). Another way is to encourage young adolescents to pursue careers in science (Tai 2006). Another suggestion is fostering a positive science identity (Stets, 2017) and shifting the culture of academic science (Hackett, 1990).

Finally, we ask: What factors contribute to inequality in science vocations? Multiple studies have identified factors contributing to inequality in science vocations. Girls with fewer experiences in science than boys at a young age, coupled with masculine cultures, lack of experience, and low self-efficacy, have all been found to contribute to greater gender gaps in certain fields than in others. Kahle (1983) highlighted the fact that girls have fewer experiences in science than boys, whilst Cheryan (2017) demonstrated that masculine cultures, lack of experience, and low self-efficacy lead to greater gender divide in computer science, engineering, and physics compared to subjects such as biology, chemistry, and mathematics.

We defined the following research questions: What specific strategies do science teachers use to promote equitable access to scientific vocations and the sustainability of these vocations in their classrooms? What can we learn about sustainability and equality in scientific vocations when we use System Dynamics and Group Modeling in participatory workshops with science teachers using archetypes such as overshoot, collapse, and privilege?

This study investigates the effects of System Dynamics and Group Modeling workshops on science teachers' understanding of scientific vocations, problem-solving abilities, and equity and inclusion practices. We hypothesized that participating in these workshops will lead science teachers to have a greater understanding of scientific vocations and effective strategies for teaching students about them, increasing the likelihood that students will develop an interest in scientific vocations, gain the ability to problem-solve, advance equity and inclusion, and explore different perspectives. Through an analysis of the existing literature and interviews with science teachers, this study seeks to understand how System Dynamics and Group Modeling workshops can enhance science teaching and generate greater interest in science vocations.

System dynamics and group modeling were proposed, combined with participatory modeling, to make science vocations more sustainable. By involving science teachers in the modeling process, the archetypes of overshoot and collapse, and the inequality archetype, we will analyze the potential effects of changing strategies on the sustainability of science vocations. Using this holistic approach, the dynamics between human behavior, technological changes, and natural forces that shape the sustainability of science vocations will be better understood. Ultimately, this can drive positive changes and greater sustainability in science.

METHOD

To test our hypotheses, we conducted an exploratory study using a combination of qualitative and quantitative research techniques. First, a comprehensive review of the scientific literature was conducted, focusing on related research, key concepts, and methodological approaches associated with System Dynamics and Group Modeling workshops. Second, a modeling workshop was conducted with a small sample of science teachers. To identify participants, we used our existing network of teachers interested in topics to improve Scientific Vocations in general. Third, we designed a series of semi-structured questions to explore teachers' experiences with the two workshops. Finally, the data collected from the interviews were coded and analyzed to identify any emerging themes associated with the impact of the workshops on teachers' understanding of scientific vocation dynamics, especially regarding sustainability and equity.

Ultimately, we provide valuable recommendations for future practice that can support science teachers in leveraging System Dynamics and Group Modeling workshops to equip students with the skills needed to engage in scientific vocations.

Initially, workshops were conducted with teachers, in which strategic resources and modes of reference around narratives about the sustainability of scientific vocations were identified. Workshops were held in the cities of Bucaramanga, San Gil, and Barrancabermeja, where narratives of the problems were discussed to identify variables and their behaviors until feedback cycles were obtained, which were later integrated into the simulation models.

With the data obtained, applications were made around fundamental concepts of system dynamics, such as feedback cycle, delay, and counter-intuitive behavior, among others. The results were then confronted against two fundamental structures: one representing the inequality between groups and the other representing the overshoot and collapse of strategic resources around training in scientific vocations.

RESULTS

Teachers from schools convened and asked about the explanations they could offer for students' success in scientific vocation training in their institutions. The exercise was inspired by the keynote address provided by Prof. Sterman at the 2022 International Systems Dynamics Conference in Frankfurt, Germany (Sterman, 2022).

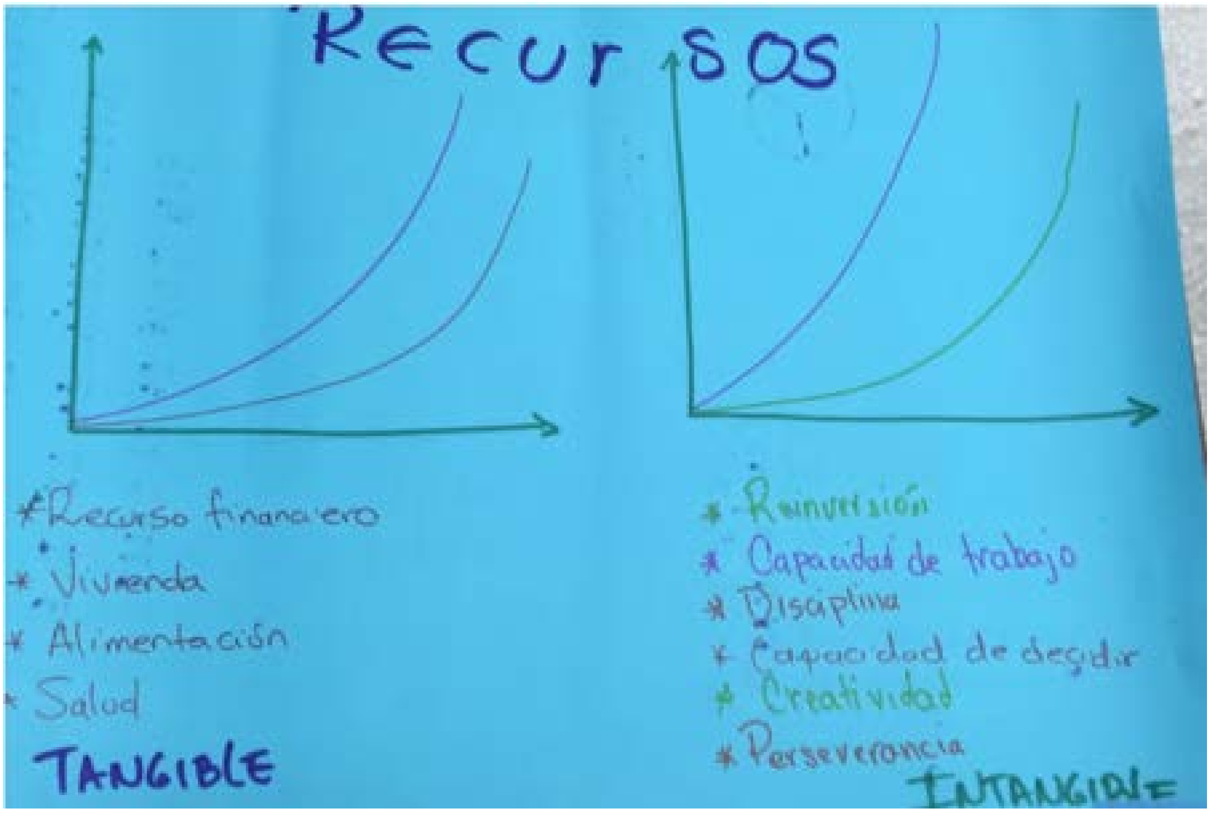

FIGURE 3. Teachers’ answers about the reference mode of tangible and intangible resources that affects Scientific Vocations.

When asked about the distinction between tangible and intangible resources, the teachers in this group responded that motivated teachers, willingness to work in research, ability to work, discipline, effort, recursive leadership, ability to develop interpersonal relationships, creativity, perseverance, and innovation are intangible resources that can affect the performance of scientific vocations, creating gaps in the feedback structure discussed during the session.

In the second workshop, the teachers were presented with a graph to discuss the sustainability of scientific vocations, which outlined students' activities in science, technology, and innovation and asked them about possible trajectories in terms of time, from maintaining growth to experiencing a reduction or deterioration in these activities, as shown in the following graph.

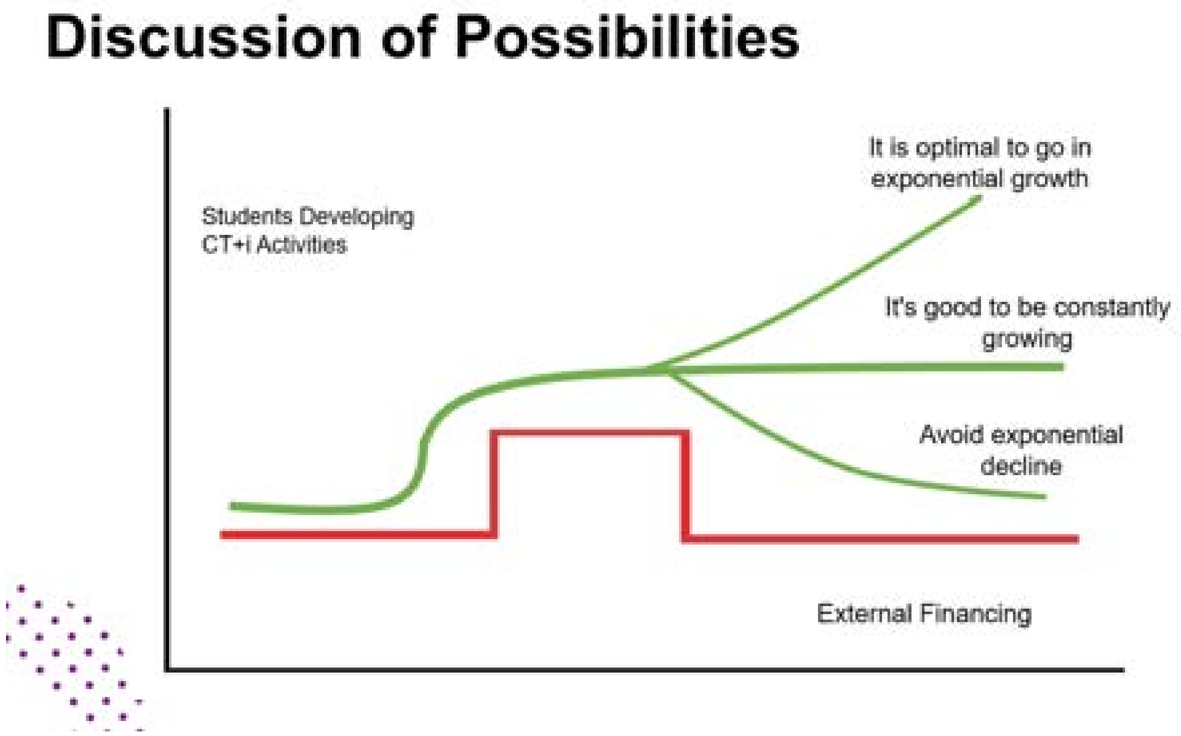

FIGURE 4. A reference mode with possible behavior about students' science and technology activities over time was used as an interactive object to promote debate about the sustainability of Scientific Vocations.

The data in the graph has identified several issues hindering the promotion of scientific vocations. These issues include limited time, inadequate institutional structures, poor data management, lack of resources and support for leaders in the community, inadequate learning spaces, inadequate preparation of teachers, lack of incentives, excessive theoretical load in classes, little to no interest from teachers, students, and parents, and a decrease in scientific vocation and interest in acquiring scientific knowledge. It is clear that these issues must be addressed in order to encourage and promote the uptake of scientific vocations.

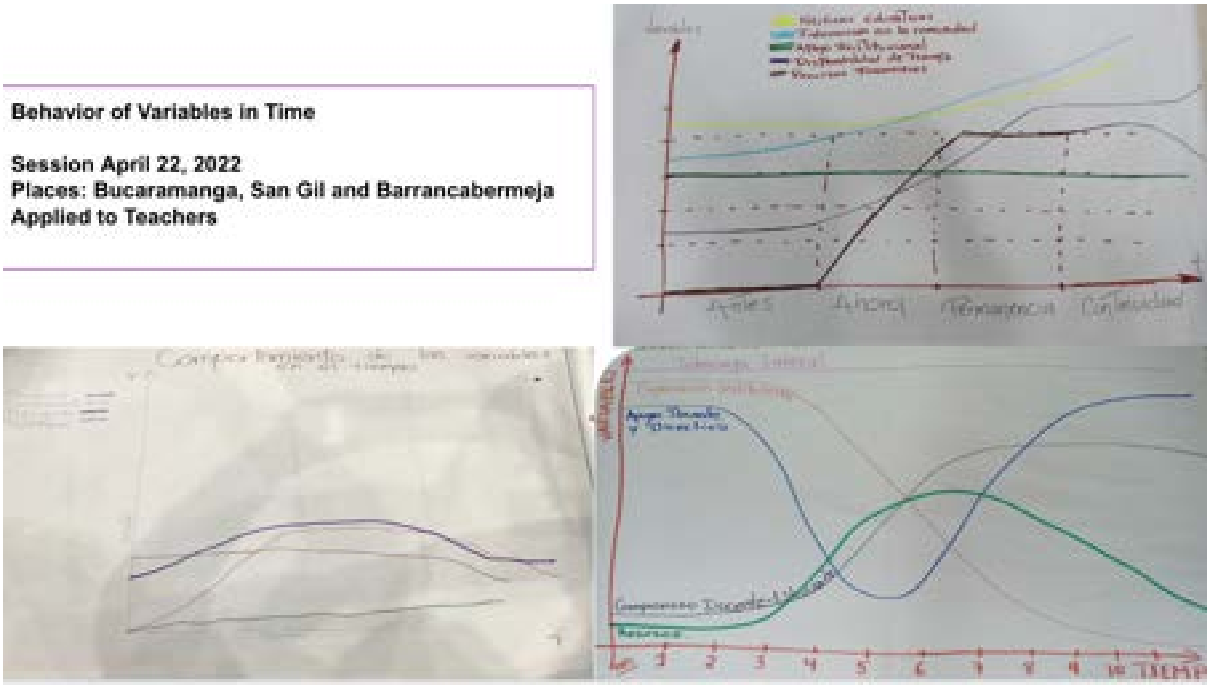

FIGURE 5. Selected photos with the actual reference modes of variables by teachers regarding scientific vocation sustainability.

Based on the identified variables, the teachers were asked to identify the most important feedback cycles. The following is a compilation of the feedback cycles identified in workshops conducted in Bucaramanga, San Gil, and Barrancabermeja.

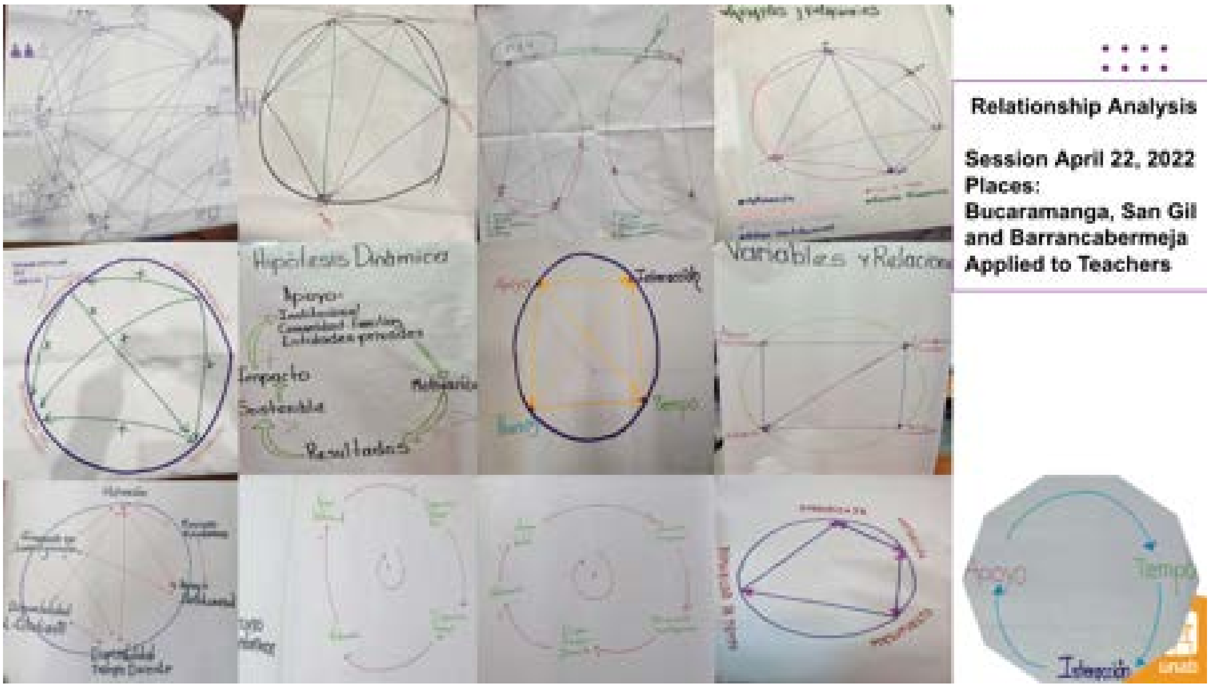

FIGURE 6. The selected feedback loops proposed by teachers liked variables affecting Scientific Vocation.

Subsequently, we processed the data to identify the most commonly found feedback cycles identified during the workshops.

The archetype of overshoot and collapse suggests that the availability of a strategic resource, such as scientific vocations, depends on other renewable and non-renewable resources that must be maintained to achieve the sustainability of the dependent resource (Meadows et al., 1972).

The archetype of overshoot and collapse helps us to comprehend how the availability of one or more crucial resources, whose dynamics are not fully understood, are essential for the maintenance of a central resource: in this scenario, the number of scientific vocations.

Initially, a dynamic hypothesis was proposed based on the archetype of overshoot and collapse, where two balance cycles and three reinforcement cycles were identified, which show how scientific vocations depend on strategic resources such as high school students, elementary students, university students, and teachers. Furthermore, the hypothesis allows us to see how these resources are intertwined and essential for the maintenance of resources, such as the number of projects that in turn depend on the existence of interested students as well as teachers to form them.

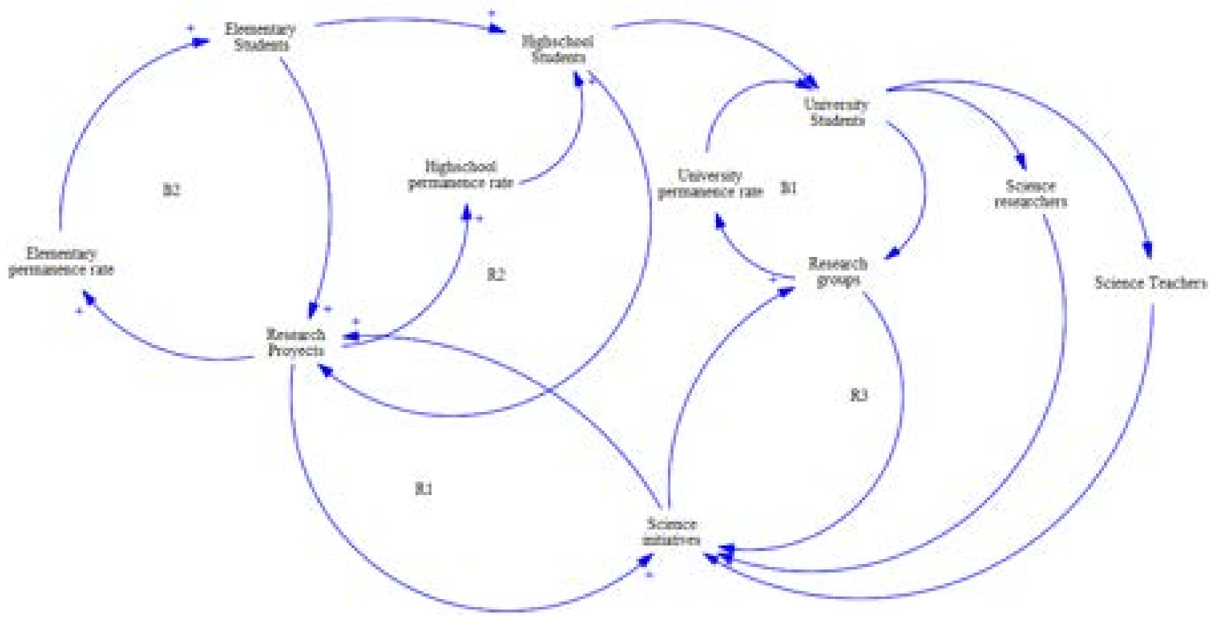

FIGURE 7. Dynamic hypothesis about the scientific vocation process.

The model represents the behavioral dynamics between students and the variables fed into science programs. These variables were class science projects, science seedlings, science researchers, and science teachers.

We have the following feedback loop: R1 Promotion of research projects in elementary students: This causal loop shows how promoting science initiatives increase the number of elementary students' research projects. R2 Increased retention and interest in science. This reinforcement cycle shows how science projects increase school permanence and interest in science and increase the number of students in science projects. R3 Promotion of research seedlings: this cycle shows the connection between the science initiative and the research groups as promoters of programs linked to science research and development.B1 Increase of research groups and university students in science, this feedback loop shows how the greater the number of research groups, the greater the permanence and interest of university students. Finally, B2 presents how an increase in research groups and elementary school students in science. This feedback loops how the greater the number of research groups, the greater the permanence and interest of the elementary school students.

Therefore, with these two balancing and three reinforcing loops, the relationship between research projects, qualified high school and university students, and adequate teachers is highlighted, allowing us to understand how scientific vocations depend on these key resources for sustainability.

Scientific vocations are the central resource for powering sustainable development through the availability of interconnected strategic resources. However, to further comprehend and take advantage of their potential, we must understand the management of resources that support improved sustainability.

Research programs are created and completed according to their connections to other strategic resources such as finances. Understanding and utilizing these resources to improve sustainability is possible through good management.

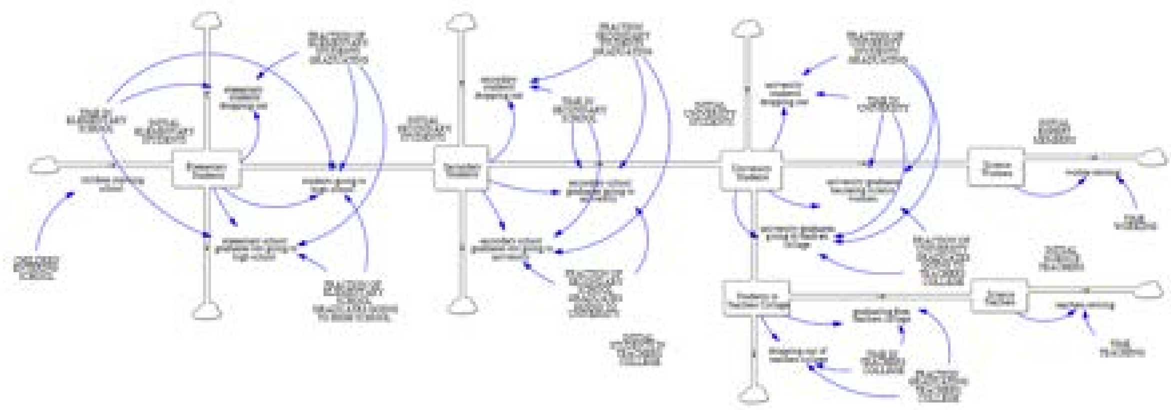

FIGURE 8. Stocks and Flows about Scientific Vocations as the central resource powering sustainable development through the availability of interconnected strategic resources.

The following diagrams show the structure of the educational pathway in Colombia from primary to university levels, with a specific focus on those who choose to pursue a scientific career or enroll in science teacher training programs.

Figure 8 shows the pathways that students take from primary to secondary school with potential dropout points at each stage. This illustrates the different factors that affect students' educational trajectories, the potential for success or failure at each point in the system, and the potential pathways after leaving school.

This figure shows how students progress from primary school to secondary school and either continue on to universities or drop out at any stage, whether through abandonment or after completing secondary school but not continuing to university. The figure shares the same central structure for those who are entering university and those who have finished their university career decide to move on to university, with the difference being those who decide to work as scientists during their university studies or those who finish university and choose to become science teachers. This figure shows the need to take care of these teachers as strategic resources to maintain the availability of scientific vocations.

Science teachers play an imperative role in connecting young people to science-related careers, as they can link the various elements of the scientific process, from primary school learning to professional training after university, to foster scientific vocations and desire among the youth, ultimately helping reduce school dropout rates and increasing their interest in science-related fields.

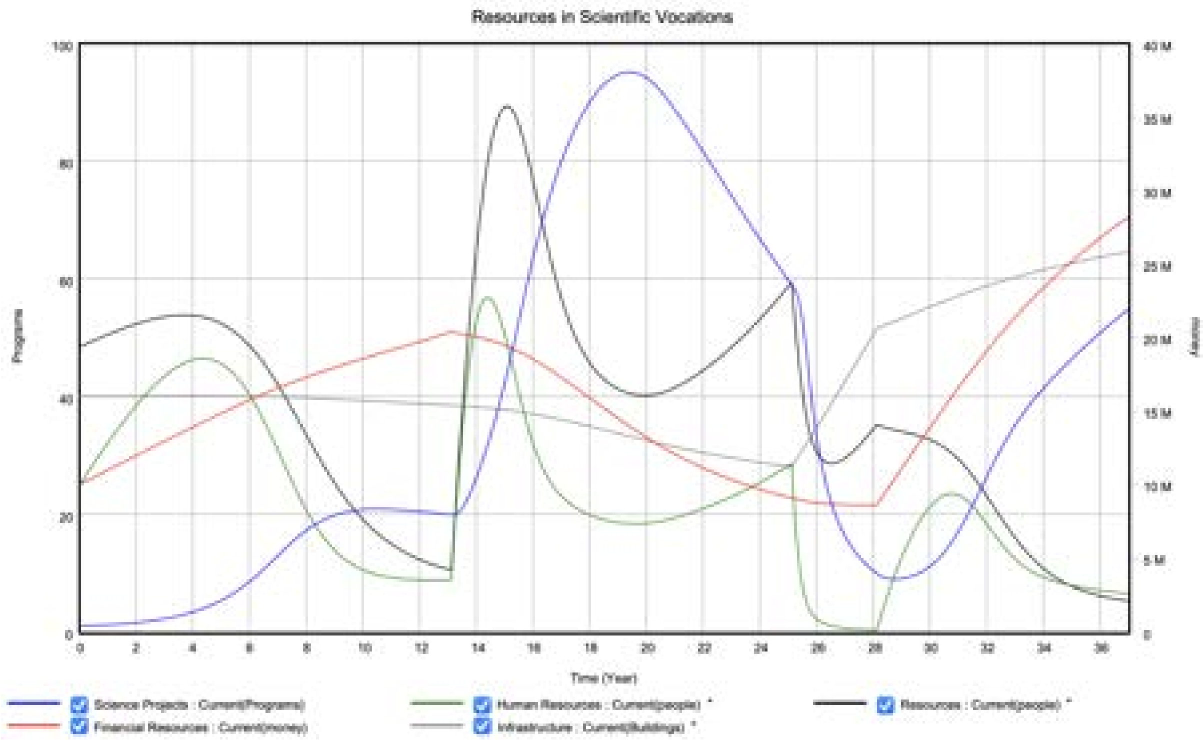

FIGURE 9. Simulations of coupled resources supporting Scientific Vocations showing Coupled Overshoot and Collapse behavior.

After conducting two workshops with teachers involved in the formation of scientific vocations in the Department of Santander, Colombia, the teachers were found to possess an individualistic mindset that favors individual decisions over their environment. However, by applying archetypes such as inequity, overshoot, and collapse, they were able to identify tangible and intangible resources that might cause inequity or sustainability problems. Simulation models were then developed to integrate the most important elements of the system, leading to the conclusion that the sustainability of scientific vocations depends on multiple nested resources including teachers, financial resources, and tangible intangibles.

DISCUSSION

This study was conducted with teachers involved in scientific vocations in the Department of Santander, Colombia, to assess their mindset and ability to identify inequities or unsustainable practices. The study found that teachers have an individualistic mindset that predisposes them to make decisions independently of their environment. This behavior can have positive outcomes, but it may also hinder their ability to identify and address issues such as inequity and unsustainability.

The study also found that teachers were able to identify tangible and intangible resources that may contribute to such issues by applying archetypes such as inequity, overshoot, and collapse. These resources were used to develop simulation models that integrate the key aspects of the system to understand its sustainability.

The study concluded that teachers play a vital role in understanding and improving sustainability in scientific vocations. It is essential that teachers have access to the necessary resources and support to identify and develop sustainable practices. Equipping teachers with the skills and knowledge to identify and promote sustainability and equity will ensure that scientific vocations continue to grow and progress in the Department of Santander and elsewhere.

The study also suggests that participatory modeling mechanisms with system dynamics can be an effective tool for identifying the causes of inequity and unsustainability in scientific vocations and the fundamental resources needed to sustain them. By presenting teachers with archetypes such as collapse and overflow, they can gain much-needed insight into their own behaviors, roles, and practices. With this knowledge, simulations can be created to study the impact of these resources on the number of scientists who sustain their vocations.

The study calls for further research on the effects of modeling processes, such as system dynamics, on student engagement and participation, as well as on their cognitive understanding of the behavior of scientific and social systems. With deeper insight, teachers can create more effective strategies for supporting equity in their classrooms, fostering greater interest in STEM for their students. Additionally, research should be conducted on the effects of system dynamics on students' understanding of STEM concepts.

CONCLUSIONS

This research suggests that teachers have a major role to play in improving sustainability in scientific vocations. By engaging teachers in activities such as simulations and the application of archetypes, we can equip them with the skills and knowledge to identify and promote sustainable practices. This will help to move scientific vocations forward in the Department of Santander and beyond, while also helping to bridge the gap between academic learning and practical solutions.

The research also suggests that system dynamics can be a highly effective tool for understanding, uncovering, and addressing the causes of inequity in scientific vocations and providing a clearer picture of the resources needed to sustain them. Through the use of archetypes and simulations, teachers can gain valuable insights into the causes of inequity and unsustainability in scientific vocations and the resources needed to sustain them.

To further increase their impact, future research should explore the effects of system dynamics on teachers' and students' engagement and participation, as well as their cognitive understanding of the behavior of scientific and social systems.

REFERENCES

Alasia, A. & Magnusson, E. (2005). Occupational skill level: The divide between rural and urban Canada.

Astalini, A., Kurniawan*, D.A., Darmaji, D., & Anggraini, L. (2020). Comparison of Students Attitudes in Science Subjects In Urban And Rural Areas.

Cheryan, S., Ziegler, S.A., Montoya, A.K., & Jiang, L. (2017). Why Are Some STEM Fields More Gender Balanced Than Others? Psychological Bulletin, 143, 1–35.

Dopico, E. (2017). Waking up scientific vocations. New Trends and Issues Proceedings on Humanities and Social Sciences.

Hackett, E.J. (1990). Science as a Vocation in the 1990s: The Changing Organizational Culture of Academic Science. The Journal of Higher Education, pp. 61, 241–279.

Hulleman, C. S., & Harackiewicz, J. M. (2009). Promoting interest and performance in high

Kahle, J.B., & Lakes, M.K. (1983). The myth of equality in science classrooms. Journal of Research in Science Teaching, 20, 131-140.

Kryst, E.L., Kotok, S., & Bodovski, K. (2015). Rural /urban disparities in science achievement in post-socialist countries: The evolving influence of socioeconomic status. Global education review, 2, 60-77.

Meadows, D. H., Meadows, D. L., Randers, J., & Behrens III, W. W. (1972). The limits to growth-club of rome.

Mupezeni, S., & Kriek, J. (2018). Out-of-school Activity: A Comparison of the Experiences of Rural and Urban Participants in Science Fairs in the Limpopo Province, South Africa. EURASIA Journal of Mathematics Science and Technology Education.

Newby, T. J. (1991). Classroom motivation: Strategies of first-year teachers. Journal of school science classes. Science, 326(5958), 1410–1412.

Sterman, J.D. (2002). Business dynamics: Systems thinking and modeling for a complex world.

Stets, J.E., Brenner, P.S., Burke, P., & Serpe, R.T. (2017). The science identity and entering a science occupation. Social science research, 64, 1-14 .

Tai, R.H., Qi Liu, C., Maltese, A., & Fan, X. (2006). Planning early for science careers Science, p. 312, 1143–1144.