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Development of scientific competence in the context of an integrated curriculum

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ABSTRACT

Early exposure of medical students to scientific research offers numerous benefits throughout their careers, fostering the development of future researchers. To analyze the training process of medical students in scientific research by evaluating acquired skills and the effectiveness of teaching methods used in the medical course for developing these competencies. Exploratory-descriptive study with a quantitative approach, involving 138 medical students in Brazil, enrolled in a program with an integrated curriculum and active learning methodologies. Participants completed a questionnaire grounded in the 7 competencies of a researcher. The majority (55%) were in the basic cycle, 27% in the clinical cycle, and 18% in medical internship (MI). Competencies related to critical analysis, hypothesis formulation, and results sharing are strongly developed in tutorial moments (TM) and medical skills and communication (MSC) activities. Conversely, the MI tends to develop these competencies to a lesser extent. The study provided an overview of the incorporation of scientific research assumptions into the analyzed curriculum, concluding that the integrated model and active methodologies are strengths in developing scientific competencies. Although the sample size is a limitation, the study offers a basis for future research on the topic.

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1. INTRODUCTION

In the contemporary context, science has been widely recognized, and scientific production has grown exponentially around the world. The wealthiest and most influential nations consider technological advancements and independence as crucial factors for increasing scientific research. In this context of significant development, research plays a fundamental role overall and, specifically, in health practices, particularly in medicine.

Research activities in undergraduate programs are the best way to introduce students to future scientific research practice. Therefore, training researchers is also an objective of academic education in the medical field, as research expands knowledge and generates science that benefits humanity. However, the importance of scientific research for doctors extends beyond the evolution of their scientific skills. Students involved in research are proven to have a higher likelihood of publishing high-quality scientific papers, achieving professional satisfaction, and obtaining greater academic stability [1]. Thus, it is essential that all students develop competencies and actively engage in research to stay updated and supported by high-quality evidence as future professionals [2].

The term "competence" is associated with being "competent". To compete, one must be competent, and to be competent, one needs skills. "Competence" is also synonymous with capacity, attribute, or ability.

All these concepts relate to the individual and what they are capable of achieving [3]. Given the diversity of meanings and the lack of clarity surrounding the words "skills" and "proficiencies", we will use the concept of "competencies" to refer to the skills, proficiency, or capacity that a scientist must possess.

Scientific skills, or more specifically, skills in scientific processes such as observation, hypothesis formulation, conducting experiments, and so forth, are among the essential elements for creating a scientific society [4]. The development of all these skills is what we refer to as "scientific process skills", which are always associated with scientific research [4]. Different researchers provide various sets of competencies that should be included in scientific process competencies [5]. Friedl and Koontz [6] suggested 6 process skills namely observing, inferring, communicating, classifying, measuring, and experimenting. However, in the most common definition of science, process competencies contain 2 levels of skills namely basic competencies and integrated competencies [4], [7].

The development of scientific competence during undergraduate studies serves as a tool in training qualified professionals, expanding their interaction with other professionals and promoting multidisciplinary. In addition to encouraging students to become researchers in an area with significant public utility, it provides students with critical thinking skills to evaluate the quality of publications and infer the validity of new discoveries. Therefore, training for scientific production contributes to professional development by stimulating the growth of technical, ethical, research, and innovation competencies, especially when applying science to address global challenges.

However, it was in the 1990s that the discussion emerged about proposing scientific initiation as a formal discipline [8]. Today, its inclusion in the curriculum has become a significant recommendation from bodies that regulate undergraduate and postgraduate education. Even though research should be a fundamental activity in medical education [9], there is a deficiency in students' access to activities related to scientific initiation [10]. The reasons are varied, including a lack of understanding of the benefits of research during undergraduate studies [2] and insecurity due to a lack of prior knowledge for the activity. Although there has been an absolute numerical increase in Brazilian scientific production in recent years, this volume primarily comes from postgraduate programs [9], further highlighting the gap in research activities and knowledge production during undergraduate studies.

Thus, modern medical education must be more comprehensive than it is currently [11]. Currently, it aims to create new theories and reflections, change paradigms and foster new perspectives in scientific research through meaningful learning, employing active theoretical and practical methodologies [10]. This contributes to the expansion of the scientific community and the production of qualified human resources for the transformation of society [12].

Teaching, research, and extension are, according to Resende *et al.* [10], inseparable, with the quality of undergraduate education being directly proportional to the generation and mastery of knowledge, not merely its transmission. It is known that undergraduate research projects typically introduce students to research activities, but retaining them remains challenging. It is important to understand that scientific training contributes to the intellectual, moral, critical, and creative development of students [13]. It is also recognized that, when analyzing students' opinions, there are indications of significant issues still to be addressed in education, mainly related to the distribution of financial resources, lack of institutionalization, and encouragement of scientific study [14].

The World Federation for Medical Education (WFME) discusses a consensus on the minimum requirements for recommended research practices. Medical schools should teach the principles of the scientific method throughout the curriculum, including analytical and critical thinking, medical investigation methods, and evidence-based medicine; and standards for quality improvement, with a curriculum that includes elements of original or advanced research, mandatory or elective analytical studies, and experimental studies [15]. In this sense, regulatory bodies in medical education encourage research. For example, in the United Kingdom, the general medical council's outcome for clinical research and studies states that "Newly qualified doctors should be able to develop methods and approaches for medical research and integrate them with a range of information sources used to make decisions about healthcare," [16].

In light of this scenario, several unresolved issues concerning the topic are highlighted, such as: the current integration of research into medical curricula, early involvement of students in research activities, difficulties in developing competencies in the field, student involvement only in postgraduate studies, lack of incentives for students to conduct research, among other issues. This led to the idea of researching the training of medical students, focusing on the development of scientific competencies for research and knowledge production during undergraduate studies, given its significant relevance in forming competent professionals. In this context, the guiding questions of this study are: What do students identify about the process of training for scientific research? How does the training process occur in relation to the development of competencies related to research and scientific production? What can be done to modify the current scenario?

To answer these questions, the objective of this study is to analyze the training process of medical students regarding the development of competencies related to research and scientific production. This study investigated the effects of the teaching method adopted in the medical course and the competencies acquired by students related to research and scientific production. Another objective was to identify strengths and weaknesses in the training process for scientific research.

2. METHOD

This study is exploratory-descriptive research with a quantitative approach. A total of 138 medical students from a program with an integrated curriculum and active teaching-learning methodologies at a higher education institution (HEI) located in Curitiba, Paraná, Brazil, were invited to participate, covering students from the 1st to the 12th semester. At this institution, the following curricular units are developed over the first 8 semesters: integrative seminar (IS), community-teaching integration (CTI), medical skills and communication (MSC), and tutorial moments (TM). In the 9th, 10th, 11th, and 12th semesters, the medical internship (MI) takes place, involving mandatory practical placements.

The IS curricular unit is implemented at the end of each semester as a time for presenting results and work produced during the semester on relevant topics. The CTI unit involves developing links between the college, services, and the community, along with practical research activities. The MSC unit focuses on developing communication skills, teamwork conceptualization, and deepening clinical reasoning and diagnostic processes. TM are small group classes led by a tutor-teacher, forming a central process in problem-based learning (PBL), where students are guided to solve a problem. The MI encompasses the last 2 years of the medical course, during which students undertake mandatory placements, applying all content learned throughout the course to real-life situations.

A structured questionnaire on Google Forms was sent to participants via WhatsApp and email. It included 28 questions, with the first 7 related to sociodemographic data and 21 questions regarding scientific competencies. These questions were theoretically based on the principles outlined by Tovar [3] concerning the nine competencies of a researcher, referred to by the author as the Luis Antonio Rivas Tovar (LART) model, and on the model used by Mesías *et al.* [17], which discusses the seven competencies of a researcher.

Participants were asked to respond to each question for the five curricular units. The response options followed the Likert scale model, with five response choices for each question: strongly agree, agree, undecided/not applicable, disagree, and strongly disagree. The questions were formulated based on the theoretical framework of Mesías *et al.* [17], with some adaptations. The questions addressed the 7 main scientific competencies, each with three indicators, which are i) explore facts and phenomena, ii) analyze problems, iii) formulate hypotheses, iv) observe, recognize, and organize information, v) use different methods of analysis, vi) evaluate methods, and vii) share results, as in Table 1.

The collected data were tabulated and analyzed using R software version 4.2.3. R is a programming language and statistical computing environment widely used in the medical field. It allows for efficient and precise data analysis, graph creation, and statistical testing. To examine the relationship between academic cycles and the development of scientific competencies, study years were grouped into basic cycle (1st, 2nd, 3rd, and 4th semesters), clinical cycle (5th, 6th, 7th, and 8th semesters), and MI (9th, 10th, 11th, and 12th semesters). The Likert scale was used with responses: agreement (total or partial), indifference/not applicable, and disagreement (total or partial). Comparisons between groups were made using significance tests, with p-values ≤ 0.05 considered statistically significant.

Table 1. Competencies and indicators analyzed according to Mesías *et al.* [17]

Competency	Indicator
1 - Explore facts and phenomena	a) Whether the student reads or listens to explore the phenomenon
	b) Uses different sources to explore phenomena
	c) Makes inferences to establish the phenomenon and the problem situation
2 - Analyze problems	a) Whether the student uses different sources to analyze a problem
	b) Proposes and constructs solutions for the identified problems
	c) Assists in selecting meaningful information to solve a problem
3 - Formulate hypotheses	a) Helps to develop preliminary assumptions
	b) Summarizes the elements to be studied
	c) Explains how to approach the elements contained in the hypothesis
4 - Observe, recognize, and organize information	a) Distinguishes the data collected during observation
	b) Captures the meaning of the collected information
	c) Establishes, understands, and contrasts the collected data
5 - Use different methods of analysis	a) Identifies and distinguishes the different components of the analysis
	b) Organizes the parts that compose a problem
	c) Assists in recognizing the implicit meanings in a problem
6 - Evaluate methods	a) Assesses and discriminates the results obtained
	b) Assists in choosing results based on rational foundations
	c) Verifies the value of the evidence
7 - Share results	a) Expresses their own ideas regarding the results
	b) Assists in conveying confidence and conviction in their speech
	c) Demonstrates preparedness in the presentations they make

3. RESULTS AND DISCUSSION

The study obtained 138 responses, of which 2 were excluded for not meeting eligibility criteria. Therefore, the final sample consisted of 136 participants. Among the participating students, ages ranged from 18 to 42 years, with the majority between 22 and 26 years. The students were predominantly female (72.8%). Regarding their stage in medical school, 55% were in the basic cycle (1st to 4th semesters), 27% in the clinical cycle (5th to 8th semesters), and 18% in the MI (9th to 12th semesters).

When analyzing the students' potential prior participation in a research group, the majority (56%) reported that they had not participated, while 44% indicated that they had been involved in a research group. Regarding scientific publication, 59% had never published, and 41% had published at least one scientific paper. Concerning extracurricular activities related to research, 57% responded negatively, while 43% responded affirmatively. Following the sociodemographic data, students completed a questionnaire consisting of questions related to the competencies established by the theoretical framework used, as demonstrated in Table 1.

The results related to the 1st competency indicate that students possess strong listening skills, collaborate and work well in teams, carefully observe materials, and establish/formulate questions. The lowest agreement with this competency occurred during the MI across all 3 indicators. Regarding the 2nd competency, the data show that the lowest agreement with this competency occurred during the MI across all three indicators, while the highest agreement was observed during the TM. Records suggest that during the MI, it may be necessary for instructors to provide resources and tools that allow for a deeper analysis of problems, whereas TM are opportunities where, in addition to understanding phenomena, students explain and construct knowledge, build meanings, compare and interpret different sources of information, with the aim of developing their own understanding of the researched phenomena. It is in this competency that students engage in the development of scientific thinking, the appropriate purpose of science education, facilitating complex learning scenarios where decision-making, critical, and proactive attitudes are demonstrated.

The results related to the 3rd competency reveal that students make preliminary assumptions, summarize the elements to be studied, and explain how to approach the relationships between the elements contained in the hypothesis. They also seek solutions for each hypothesis; respond effectively; and report topics to analytical questions and contextual knowledge. The lowest agreement with this competency occurred during the MI in all three indicators, while the IS and CTI curricular matrices had slight agreement, and the TM and MSC had the highest agreement.

The data indicate that for the 4th competency, there was high agreement in the matrices CTI, MSC, IS, and the TM, with greater indifference during the MI. This finding suggests that this competency could be strengthened by facilitating real experiences for students, encouraging the construction of new knowledge through actions such as observing, collecting, and organizing information, which are fundamental skills in scientific development. Another associated aspect that needs to be highlighted is the presence of significant experiences, where students should have the attitude and willingness to extract meaning from new learnings; this, in turn, impacts and destabilizes their previously established cognitive structures.

The results related to the 5th competence show that, for the indicator "identify and distinguish the different components of the analysis", there were indifferent responses in the MSC, CTI and IS matrices. In addition, there was slightly greater agreement in the TM and greater disagreement during the MI. For the subsequent indicators, agreement was observed in all matrices, except during the MI.

For the 6th competency, the indicator "assist in choosing results based on rational foundations" showed the highest disagreement in the curricular matrices MSC, CTI, TM, and IS, and was indifferent during the MI. These findings highlight the need to evaluate methods used to obtain results for arguments that allow early detection of problems. The importance of verifying the value of evidence as part of method evaluation can be emphasized, as it demonstrates the process and explains the reason for the results. For the indicators "compare and discriminate the results obtained" and "verify the value of evidence", there was broad agreement in the curricular units IS, MSC, CTI, and TM, with indifference during the MI. These findings show that students have the ability to compare and discriminate results obtained after a followed process, ensuring understanding of the changes generated, consistent with criteria of clarity and coherence. Furthermore, they interact with evidence, demonstrate interest in verifying hypotheses, and exhibit critical thinking.

Finally, the results related to the 7th competency indicate that students feel confident in sharing results throughout the integrated curriculum, developing skills to share ideas. The lowest agreement with this competency occurred during the MI. It was identified in all three indicators, while the other curricular units showed broad agreement. Didactically, Table 2 presents the percentages related to each curricular unit by analyzed competency.

The results indicate that the competency of exploring facts and phenomena is most developed in the TM (85%) and the IS (74%), with less emphasis during the MI (47%). The ability to analyze problems is strongly developed in the TM (92%) and MSC activities (82%), but is less emphasized during the MI (52%). Similarly, formulating hypotheses is well-developed in the TM (86%) and MSC (82%), with the lowest development occurring during the MI (51%). The skill of observing, recognizing, and organizing information is most developed in the TM (76%) and shows the least development during the MI (46%). The use of different methods of analysis is emphasized most in the TM (81%) and MSC (78%), with less focus during the MI (44%). Competency in evaluating methods is balanced overall but less intense during the MI (38%), with greater development in the TM (64%). Finally, the competency of sharing results shows high development across several curricular units, notably in MSC (85%) and TM (85%), while the MI has a lower percentage (50%).

Table 2. The five curricular unit's percentages

Competency	IS (%)	MSC (%)	CTI (%)	TM (%)	MI (%)
1 - Explore facts and phenomena	74	73	61	85	47
2 - Analyze problems	68	82	73	92	52
3 - Formulate hypotheses	69	82	69	86	51
4 - Observe, recognize, and organize information	67	71	66	76	46
5 - Use different methods of analysis	68	78	70	81	44
6 - Evaluate methods	61	61	56	64	38
7 - Share results	74	85	82	85	50

The data suggests that competencies related to critical analysis, hypothesis formulation, and results sharing are strongly emphasized in the TM and MSC activities. Conversely, the MI tends to develop these competencies with less intensity, possibly due to its more practical and application-focused nature at this stage of the course. A study of general surgery residents aimed at understanding research productivity and success factors shows that prior research exposure and experience with publication are associated with higher productivity and research impact. This finding supports the importance highlighted in this study of introducing students to research from the 1st year, as evidenced by the high percentages found across all analyzed curricular units [18]. The distribution of these competencies may reflect an intention to strengthen different skills at various stages of medical education, focusing on building specific competencies at each phase of the course.

Among all analyses, the only criterion that showed greater disagreement across all curricular units (IS, MSC, CTI, TM, and MI) was the 6th scientific competency evaluating methods specifically "assisting in the selection of results based on rational foundations". Disagreement percentages were 46% in the IS, 50% in MSC, 48% in CTI, 49% in TM, and 24% in the MI. According to Mesías *et al.* [17], this competency requires students to compare and discriminate the results obtained from a process, ensuring an understanding of the changes according to criteria of clarity and coherence. This competency is not among the most recognized or frequently addressed in the classroom, possibly because some competency performances are presented at high levels, while those associated with evaluating the value of evidence show divergence, likely due to a tendency to accept results without thorough analysis or investigation.

The national curricular guidelines for undergraduate medical programs, most recently published in 2014, establish the principles, foundations, and objectives of medical training. They emphasize that to promote scientific and critical thinking and support the generation of new knowledge, the following actions are expected: using work challenges to stimulate and apply scientific reasoning, critically analyzing sources, methods, and results to evaluate evidence, identifying the need for new health knowledge production through dialogue between practice, scientific output, and available technological development; and fostering scientific and technological development focused on addressing individual and collective health needs through the dissemination of best practices and supporting socially relevant research [19].

Hoffman explores a new approach to the macrostructure of a medical school's curriculum based on competencies and less constrained by time and curricular activities. The educational plans included various combinations of educational activities, always incorporating research for educational advancement, aligning with the studied curriculum. Although not competency-based, this non-traditional curriculum includes several opportunities for teaching and learning about scientific research [20].

Researchers should direct their investigations to address current issues. It is through continuous reflection on research practices and a well-defined model for researcher training, suited to the current economic, social, and political situation, that the creative meaning can likely be recovered. This is given the context in which research-related plans and programs are developed and determined by the characteristics of prevailing economic and political institutional models. It is necessary to make the method of knowledge construction relevant, especially for the 6th competency evaluating methods the only criterion that showed greater disagreement across all curricular units, and thanks to scientific research we are achieving more social advances every day [21].

Early exposure of medical students to hands-on research activities improves their attitude toward research and increases the likelihood that medical graduates will pursue related careers and become medical scientists [22]. This finding is in line with the results of this study, where students in the basic and clinical cycles showed greater agreement regarding the development of scientific competencies during their undergraduate education. The results of this study are in line with the study that understands that it is important to reinforce the notion that early exposure stimulates the development of research.

Miranda and Munóz [23], who studied Cuban medical education, notes that research training is primarily limited to a course on research methodology and research projects, without the development of scientific training throughout the undergraduate program. Investigative skills development is often carried out spontaneously rather than through a systematic and integrated approach within disciplines and careers, which hinders the creation of a scientific culture, a curricular limitation that needs to be addressed. In contrast, the curriculum studied here employs active teaching and learning methodologies that develop tools and actions towards educational goals. From the start of their training, students encounter problems and situations that encourage research to find answers and solutions, thus fostering a scientific culture.

Overall, when evaluating the results across all scientific competencies, the MI curriculum showed the lowest level of agreement, followed by the IS, ITC, MSC, and TM. There is also a belief in the need for courses and events aimed at disseminating scientific knowledge, as well as the early involvement of undergraduate students in research. This involvement would encourage, enable, and facilitate students' entry into scientific initiation, allowing them to gradually build their curricula and become knowledge multipliers even after their training. Such an approach would integrate their clinical knowledge with scientific updates in patient treatment and in disseminating information to other team members [24].

In this study, medical interns showed less agreement regarding scientific competencies. It is noted that regularly participating in scientific events or courses can help maintain critical thinking, data analysis, and scientific communication skills, especially when students are limited to practical activities. In this sense, research conducted using the student attitude towards research (SAR) scale among medical students in Saudi Arabia revealed that, although they believe research is important, their attitudes were not positive. This highlights the urgent need to establish research programs in health education [25].

Several factors negatively impact scientific training. For example, we can mention the lack of a didactic approach in conducting students' scientific work, reflected in a weak theoretical-methodological orientation for their development in this activity. The didactic action in this process is characterized by prioritizing the fulfillment of task schedules and the achievement of expected results to the detriment of the development of investigative skills that future professionals will need [26].

Regarding TM, which have as a more general objective the systematic monitoring of students, always preceded by a tutor who guides and directs the development of knowledge, there was greater agreement in the students' responses in all competencies compared to other curricular units. This finding reinforces our study that states that early exposure to research in medical school can provide students with a positive influence on engagement with research. It can be stated that early exposure allows them to make an informed decision about participating in research at the beginning of medical school, potentially providing students with a positive influence on engagement with research [27], data that corroborate the results of this research.

On the other hand, Mass-Hernández *et al.* [28] states that research plays a crucial role in scientific advancement and is essential for strengthening medical learning and practice. Therefore, it is vital to instill and promote the development of critical and rational thinking among medical students from the beginning of their professional careers, to achieve better training in research and evidence-based medicine. However, to overcome the many challenges that persist today and ultimately achieve active student participation in research, it is necessary to develop appropriate strategies and measures to facilitate this process.

One of the most important aspects of adopting a research culture during medical education is creating a curriculum that encourages students, from the start of their careers, to reflect on the basic principles and parameters of research, including epidemiology, biostatistics, research methodology, and scientific publication. Participation in research during medical school is associated with acquiring greater research-related skills, better clinical outcomes in health contexts, and higher scientific productivity in the future. Medical students themselves show a positive attitude and perceive early medical research as a valuable tool when applying for specialized training, and also consider it very useful for becoming more complete and qualified future professionals [29].

The contribution to the field of education is represented through the analysis and identification of the importance of scientific research in the training of medical students, and is highlighted by early exposure to scientific research and the skills developed by students within the research context [30]. This is significant not only because research is a core process of the university, but also because it represents a specific function of professional work that prepares graduates to successfully meet the demands of contemporary scientific and technical development [26]. In summary, the contribution to the field of education is expressed in how the medical curriculum, to varying degrees, promotes the development of essential scientific competencies for professional practice, indicating potential for improvement and continuity in the preparation of future researchers.

4. CONCLUSION

In this study, it is concluded that within the context of an integrated medical education curriculum, the development of research and scientific production skills occurs across various curricular modules throughout the course. It is evident that the perception of what constitutes a scientific competency grows as students advance to later stages, demonstrating continuous preparation for scientific research training within this medical course. Regardless of the module in which the student is enrolled, there is evidence that the method used provides different opportunities for skill development, as indicated by the high level of agreement with questions related to scientific competencies.

The study provided an overview of the incorporation of assumptions related to the analyzed course curriculum, allowing the identification of strengths and weaknesses regarding scientific competency. As a strength, the integrated curriculum model showed a high level of agreement with activities that promote scientific training. As a weakness, there was a lack of scientific publication during the undergraduate course and a lack of knowledge about research method analysis, which may reflect a lack of encouragement from the teaching staff. As a limitation of the study, the sample size was considered moderate. However, more in-depth studies may be needed to confirm that the results indicated progress toward new knowledge by addressing a topic less explored in the scientific community and may be especially relevant for future investigations.

It is recommended to create strategies to strengthen medical research programs and curricula that promote critical and reflective thinking and develop scientific research throughout the course. This includes introducing medical research programs as part of the curriculum in all medical education institutions and ensuring that these programs effectively achieve their goals and continue to be improved, providing qualified professionals, adequate facilities, and innovative theoretical-methodological support.

Finally, our findings provide conclusive evidence that this proposed learning method is associated with offering an integrated curriculum that uses active teaching-learning methodologies and a faculty encouraged to develop research skills, fostering the development of competencies for scientific research in a dynamic and complex world. This involves developing the ability to think critically, question, investigate, and solve problems creatively based on evidence. For future research, scientific competency could be explored in depth, demonstrating that it involves a set of interconnected skills, with viable ways to enable future professionals to make informed decisions, engage in innovation, demonstrate critical thinking, and seek solutions to global problems, contributing to a more just and sustainable society.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

ETHICAL APPROVAL

For the development of this study, approval was obtained from the Research Ethics Committee (REC), under opinion number 5.066.955.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [FRV], upon reasonable request.

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