BETWEEN ALGORITHMS AND AFFECTIONS IN THE AMAZON: EXPERIENCES WITH RELATIONAL AND ARTIFICIAL INTELLIGENCE IN GUIDING UNDERGRADUATE THESIS

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Abstract:

This article explores the interplay between relational education and artificial intelligence in higher education, drawing on the supervision of two undergraduate theses completed in 2024 at Amazonas State University. The studies focused on fuzzy optimal control of the pink river dolphin (*Inia geoffrensis*) population and numerical modeling of thermal stratification in Lake Tefé - both complex projects rooted in the Amazonian context and requiring advanced mathematical and computational skills. Despite their technical demands, the success of these endeavors hinged on relational practices such as active listening, trust, progressive autonomy, and dialogue. Building on these experiences, the article discusses how artificial and relational dimension can be integrated to foster innovative, human-centered pedagogy in technical-scientific fields. A table is provided to illustrate the intersection of ecological, mathematical, territorial, technological, and relational dimensions involved in the projects.

Keywords: Academic supervision; Relational Education; Artificial Intelligence; Higher Education; Mathematical Modeling.

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Introduction

The increasing presence of artificial intelligence (AI) in higher education has sparked critical discussions about the evolving roles of educators, the nature of student autonomy, and the boundaries between human mediation and automated systems. In technical fields such as mathematical modeling and computational reasoning, AI integration often appears more intuitive due to the alignment between subject matter and available tools. However, even in these specialized domains, the relational dimension of education continues to play an essential role. Deep learning, overcoming conceptual barriers, and cultivating critical thinking depend not only on cognitive engagement but also on affective bonds, active listening, and mutual trust – core components of what is referred to as relational education.Although much of the current discourse focuses on the affordances and efficiencies of AI, there exists a latent but crucial tension between increasing technical dependence and the need for sustained human mediation. While AI systems can accelerate data processing and provide analytical insights, they are limited in their ability to interpret nuance, respond empathetically, or contextualize knowledge ethically. This tension is especially pronounced in pedagogical contexts where the formation of critical, autonomous, and socially engaged learners is paramount. Rather than viewing AI and human mediation as opposing forces, this article proposes that their integrativo – when guided by pedagogical wisdom – can yield innovative and transformative educational experiences.

Recent systematic reviews have highlighted the rapid expansion of AI applications in higher education. Zawacki-Richter et al. (2019) conducted a comprehensive review of 146 studies published between 2007 and 2018, identifying AI's strengths in tasks such as assessment and evaluation, particularly when supported by supervised machine learning techniques. Bond et al. (2023), in their meta-systematic review, emphasized the need for greater ethical considerations, collaboration, and methodological rigor in AI-driven educational practices. While AI demonstrates efficiency in automating certain academic functions, its successful implementation relies heavily on human oversight and contextual understanding.

Parallel research into mentoring and supervision underscores the enduring importance of relational practices in higher education. Nabi et al. (2024), in their systematic review examining the impact of mentoring in higher education on student career development, found that mentoring relationships provide significant benefits across multiple dimensions of student development. Their comprehensive analysis highlighted how effective mentoring contributes to career advancement, professional skill development, and enhanced academic outcomes, emphasizing the critical role of human guidance in educational contexts. Supervisory relationships are especially significant in guiding students through complex academic transitions, including thesis writing and independent research.

Despite growing interest in both AI and relational mentoring, the intersection of these two areas – particularly in contexts requiring high-level technical guidance – remains underexplored. Meta-analyses indicate that effective mentoring correlates with improved student outcomes, suggesting potential for examining how AI can complement rather than replace these human connections. This article draws on the supervision of two undergraduate theses completed at Amazonas State University in 2024, offering insights into how relational and artificial intelligence can be integrated to support innovative, human-centered pedagogy in technical-scientific disciplines.

Both theses addressed complex environmental modeling problems rooted in the Amazonian context: one focused on fuzzy optimal control of pink river dolphin population, and the other explored numerical modeling of thermal stratification in Lake Tefé. These projects required advanced mathematical and computational skills, yet their success hinged on continuous relational processes that extended beyond technical instruction. By documenting and analyzing these experiences, this study aims to contribute to the ongoing discourse on pedagogical innovation, particularly in socio-territorially challenged regions like the Brazilian Amazon.

The Role of Relational and Affective Practices in Technical Fields

In higher education, particularly in technical and scientific disciplines, relational intelligence plays a foundational role in shaping meaningful learning experiences. It can be understood as the capacity to build, maintain, and enhance interpersonal relationships grounded in empathy, active listening, affective communication, and cooperation. In academic settings marked by complexity and high cognitive demand, this form of intelligence becomes essential for creating environments where students feel safe, supported, and capable of engaging deeply with challenging material.

Scholars such as Goleman (1995) and Freire (1996) emphasize that education is, at its core, a relational process – one in which knowledge emerges through human interaction rather than mere content transmission. This perspective aligns with constructivist theories, particularly Vygotsky's (1978) concept of the Zone of Proximal Development (ZPD), which highlights how learning occurs through social mediation. The educator's role extends beyond instruction to include emotional support and cognitive scaffolding, especially when students face conceptual barriers or emotional discomfort.

This understanding gains particular relevance in technical fields like applied mathematics and computational modeling, where abstract concepts and complex problem-solving can generate anxiety, frustration, and self-doubt. Emotional bonds formed through relational practices serve as bridges, enabling students to persist through uncertainty and develop the confidence necessary for independent inquiry. As noted by Guo et al. (2025), the university professor increasingly functions as a professional whose expertise includes not only subject mastery but also the ability to mediate learning through affective engagement.

A critical and affective approach to pedagogy further reinforces the importance of emotions in the learning process. Drawing from authors such as Maturana (1990), Hooks (1994), and Zembylas (2021), this perspective recognizes that affect is not peripheral but central to educational outcomes. Learning involves trial and error, intrinsic motivation, and dialogue – processes that are deeply influenced by emotional states. Positive emotions such as curiosity and enthusiasm enhance engagement, while negative emotions like fear or anxiety can hinder comprehension and participation.

In technical supervision, particularly during undergraduate thesis work, educators must be attentive to these emotional dimensions. They must create supportive learning environments where students feel encouraged to take intellectual risks, voice uncertainties, and explore new ideas. As Hooks (1994) emphasizes, transformative education requires creating classroom spaces where students can engage authentically with challenging material while feeling supported in their learning journey. Supervisors who validate student emotions while maintaining high academic expectations foster transformative learning experiences that go beyond technical competence to include ethical and socially engaged practice.

Moreover, relational education is especially vital in socio-territorially marginalized contexts such as the Brazilian Amazon. Students in these regions often face additional cultural, economic, and logistical challenges that can impact their learning trajectories. Recognizing and integrating local knowledge, cultural backgrounds, and individual rhythms into pedagogical strategies enhances both engagement and retention. It also affirms the value of situated, embodied knowledge – a dimension frequently overlooked in traditional, cognition-centered models of education.

Thus, relational and affective practices should not be seen as supplementary to technical instruction but as integral to it. Academic supervision, particularly in demanding final-year projects, serves as a privileged space for cultivating this integration. It enables personalized, dialogical, and context-sensitive mentoring that supports students not only in mastering complex content but also in developing resilience, ethical awareness, and a sense of purpose.

By framing technical education within a relational and affective lens, we move beyond dichotomies between reason and emotion, technique and care. Instead, we recognize that deep learning in any field – especially one as cognitively demanding as mathematical modeling – requires both intellectual rigor and emotional attunement. This synthesis not only enhances academic outcomes but also prepares students to engage meaningfully with their communities and the broader world.

Artificial Intelligence and Mathematical Modeling

To understand how relational and artificial dimensions can intersect productively in higher education, we now turn to the technical domain of mathematical modeling. Artificial intelligence, particularly in the form of optimization algorithms, fuzzy systems, and computational simulations, has been playing an increasingly prominent role in research and teaching projects. In fields such as environmental systems modeling, computational techniques enable the precise representation of complex phenomena, the generation of predictive scenarios, and support for decision-making. Tools like fuzzy logic, numerical methods, and data-driven simulations have expanded research possibilities in contexts such as the Amazon, where direct access to data may be limited but environmental variables are rich and interdependent.

The integration of AI in mathematical modeling has demonstrated significant pedagogical potential, particularly through the development of comprehensive frameworks that bridge symbolic and numerical processing approaches. Dubois and Prade (1998) demonstrates how soft computing approaches can effectively address complex evaluation problems by establishing mathematical frameworks that simultaneously exploit numerical data and human knowledge in uncertain environments. Their work emphasizes that fuzzy set theory serves as a crucial interface between symbols and numbers, offering flexible tools for knowledge representation that can handle imprecision in meaning and capture shades of unspecific information. This approach proves especially valuable in environmental modeling contexts where uncertainty and imprecision are inherent characteristics of the systems being studied. Fuzzy logic systems excel in handling the ambiguity present in ecological data, allowing students to work with realistic models that reflect the complexity of natural systems rather than oversimplified deterministic approaches.

The pedagogical value lies not only in the technical skills students acquire but also in their enhanced capacity to think systemically about environmental challenges, understanding how multiple variables interact in non-linear ways while maintaining the ability to provide linguistically interpretable explanations of system behavior. This aspect exemplifies how artificial intelligence, when used wisely, can serve as a means for expanding – not replacing – students' epistemological agency.

Furthermore, the recent surge in computational modeling applications to biological and environmental systems has created new opportunities for interdisciplinary learning in higher education. The development of systematic approaches to computational biological modeling has become increasingly important, as demonstrated by recent work on design patterns for constructing computational biological models. Herajy, Liu, and Heiner (2024) highlight how structured methodologies in computational modeling can enhance both the reliability and educational value of biological system simulations, providing frameworks that facilitate the construction of robust models across different biological scales.

As we transition to the case studies that follow, we examine how these computational tools were integrated within relational mentoring frameworks. This integrated approach not only supported the development of advanced research skills but also maintained the affective, ethical, and context-sensitive dimensions essential to transformative pedagogy.

Methodology

This study adopts a qualitative research approach rooted in autoethnographic and phenomenological methods to explore the integration of relational and artificial intelligence in undergraduate thesis supervision within higher education. Positioned within the interpretive paradigm, the research emphasizes subjective experiences and meanings that emerge through pedagogical practices (Creswell & Poth, 2018).
The methodological framework draws on Ellis and Bochner's (2000) conceptualization of autoethnography as a process that systematically analyzes personal experience to understand broader cultural phenomena. This approach is particularly suited to educational research where the researcher also functions as an educator-practitioner, offering unique insights into pedagogical interactions. The design further aligns with practitioner inquiry (Cochran-Smith & Lytle, 2009), emphasizing how educators generate knowledge through reflective investigation of their own practice.
The study focuses on two undergraduate thesis supervision processes conducted during 2024 at the Bachelor's Degree in Mathematics program at Amazonas State University. These cases were selected through purposeful sampling (Patton, 2015) due to their relevance in illustrating the intersection of mathematical modeling, computational reasoning, and relational mediation in the Amazonian context.
Data collection was integrated into the natural progression of supervision and included:

- Reflective journal entries documenting teaching decisions and student interactions.
- Electronic correspondence (email, messaging apps) between supervisor and students.
- Verbal reports, feedback sessions, and observational notes from face-to-face meetings.
- Analysis of student work submissions and developmental milestones.

These materials were analyzed using thematic analysis (Braun & Clarke, 2006), involving six phases: familiarization with data, coding, theme identification, theme review, definition, and final reporting. This method ensured analytical rigor while preserving the interpretive depth necessary for understanding complex pedagogical dynamics.
Potential limitations include researcher bias inherent in autoethnographic approaches. These were mitigated through reflexive practice and triangulation of multiple data sources, as recommended by Tracy (2010) for enhancing qualitative research quality.
By situating personal experience within broader educational discourses, this methodology contributes to what Shulman (1986) describes as the scholarship of teaching – systematic inquiry into teaching and learning that generates insights applicable beyond specific contexts.

Undergraduate Thesis 1: Fuzzy Optimal Control of Dolphin Population

The first analyzed study was titled "Fuzzy Optimal Control of the Pink Dolphin (*Inia geoffrensis*) Population in Lake Tefé Under the Effect of Extreme Climate Events." The proposal involved investigating, through a mathematical model with fuzzy logic-based optimal control, preservation strategies for this Amazonian species, considering the impacts of climate events such as prolonged droughts and rising average water temperatures.

From a technical standpoint, the work required the student to master various mathematical and computational tools: systems of differential equations, optimal control principles, fuzzy inference rules, numerical simulation algorithms, and the interpretation of ecological parameters obtained through literature review. The problem was inherently interdisciplinar – bridging ecology, applied mathematics, and socioterritorial aspects of the Amazon – and demanded significant abstract thinking and investigative autonomy.

However, it was precisely the mentoring relationship established throughout the process that enabled the student to overcome methodological and conceptual obstacles. The initial challenges arose in translating real ecological conditions into the mathematical model's parameters: quantifying population growth rates, natural mortality, and anthropogenic pressure required not only research but also carefully discussed interpretations. These moments revealed the essential role of co-construction of knowledge, where mentor and mentee collaboratively interpreted and redefined ecological indicators.

Active listening, fostering curiosity, and progressively building autonomy were crucial at this stage. Relational education practices created a safe and dialogical space that enabled the student to shift from a fixed epistemological stance – expecting precise, deterministic solutions – to a more flexible and critical engagement with uncertainty. This was especially relevant when the project reached the stage of integrating fuzzy logic into the model.

Initially, the student resisted fuzzy logic, perceiving it as imprecise and unscientific. This response exposed a common tension in technical education: the preference for clarity and closure over ambiguity and approximation. Through guided discussions, collaborative exploration of algorithmic structures, and exposure to foundational literature in soft computing, the student gradually embraced the epistemological value of fuzzy systems. This transition exemplifies how relational mentoring mediates not just cognitive development, but also ontological and epistemic transformation.

The experience also demonstrated the formative power of affective connection to place. As a resident of the municipality of Iranduba, the student brought lived knowledge of the Amazonian ecosystem into the project. This situated experience enriched the model's design and deepened the student's sense of responsibility toward the research topic. By validating this connection, the mentoring process affirmed not only cognitive achievement but also emotional engagement and territorial belonging.

Throughout the process, various strategies were employed to foster resilience and determination: sustained dialogue, clarification of technical doubts without judgment, regular validation of progress, and scaffolding the student's growing autonomy. These strategies collectively reinforced the student's self-confidence, encouraged risk-taking, and contributed to the development of scientific identity

By the end of the process, the student presented the work confidently and with conceptual mastery during the defense and began drafting an article for future submission to a journal in the field. The journey demonstrated that, even in a highly technical context, the development of cognitive skills is deeply intertwined with relational mediation, mutual trust, and the collaborative construction of meaning.

This case illustrates a productive synthesis between artificial intelligence tools – embodied in fuzzy systems and computational simulations – and the relational dimension of research supervision. Rather than operating in opposition, these dimensions worked in tandem to support both analytical rigor and human development, offering a model for ethically grounded, context-sensitive education in the age of AI.

The student's initial resistance to fuzzy logic as an "imprecise" approach mirrors broader tensions in how we conceptualize intelligence itself. Drawing on Freire's (1996) critical pedagogy, this resistance can be understood as a manifestation of what he terms "banking education" – where students expect definitive, classical answers rather than embracing the uncertainty inherent in complex ecological systems. The mentor's role in reframing the student's "relationship with knowledge" aligns with Freire's call for problem-posing education, where learners become critical co-investigators of reality.

Vygotsky's (1978) concept of the ZPD becomes particularly relevant here. The transition from classical mathematical modeling to fuzzy logic represents a cognitive leap that required careful scaffolding through the mentoring relationship. The "progressive building of autonomy" described in the case exemplifies how relational intelligence – embodied in the mentor's pedagogical sensitivity – creates the conditions for expanding the student's cognitive capabilities beyond what they could achieve independently.

The integration of computational modeling and fuzzy inference systems in this thesis raises questions about the role of artificial intelligence in educational processes. Bond et al. (2023) call for increased ethics and collaboration in AI applications in higher education, warning against approaches that diminish human agency. The dolphin population study demonstrates a productive integration where AI tools (fuzzy logic systems, numerical simulations) serve as cognitive extensions rather than replacements for human reasoning.

This aligns with Dubois and Prade (1998) and their critique of viewing artificial intelligence as separate from human reasoning capabilities. Rather than treating soft computing as an alternative to symbolic AI that emphasizes "number crunching" over explanation, their framework suggests a more nuanced relationship where computational tools serve as bridges between numerical modeling and human knowledge representation. They argue that fuzzy logic systems become instruments for exploring complex problems that would be intractable through traditional analytical methods alone, while maintaining the capacity to produce linguistically interpretable statements that can explain data rather than merely approximate it. This approach avoids what they see as a dangerous trend of reducing intelligence to pure computational processing, instead proposing that effective problem-solving requires systems capable of simultaneously learning from data and supplying explanations at a symbolic level.

The recognition of the student's local knowledge as a resident of Iranduba introduces a crucial dimension often overlooked in discussions of intelligence. Hooks' (1994) emphasis on education as the practice of freedom resonates with how the mentor "acknowledged and encouraged" the student's emotional connection to their territory. This validates Maturana's (1990) understanding of emotions and language as foundational to learning processes.

The case illustrates what Zembylas (2021) describes as the "affective turn in education." The student's sense of belonging to the riverine environment wasn't merely an add-on to their technical competencies but became integral to their research depth and authenticity. This challenges narrow conceptions of intelligence that privilege abstract reasoning over situated, embodied knowledge.

Goleman's (1995) framework of emotional intelligence finds expression in how the mentor navigated the student's initial resistance and built confidence throughout the process. The "active listening, fostering curiosity" approach demonstrates emotional intelligence in action, creating psychological safety necessary for intellectual risk-taking.

The interdisciplinary nature of the Project – "bridging ecology, applied mathematics, and socioterritorial aspects of the Amazon" – reflects key insights from Guo et al. (2025) on the role of educators as emotionally supportive mentors in higher education. The mentor had to cultivate not only technical expertise across multiple domains but also a deep awareness of how emotional support shapes students' engagement with complex, multidisciplinary content. According to Guo et al., teacher emotional support significantly influences student learning engagement by fostering academic self-efficacy and academic resilience – two critical psychological factors that enable students to persist through challenges and remain actively involved in their learning.

The adoption of fuzzy logic to handle "data uncertainty – a typical characteristic of ecological modeling in regions like the Amazon" presents a fascinating paradox. The most precise mathematical tool for this context was one that embraces imprecision. This echoes broader questions about intelligence: Is true intelligence the ability to provide definitive answers, or the capacity to navigate uncertainty with sophistication?

The computational modeling described by Herajy, Liu & Heiner (2024) in biological systems research supports this nuanced view. The case study demonstrates how artificial intelligence tools can enhance rather than replace human judgment, particularly in contexts where traditional binary logic proves inadequate.

The synthesis of relational and artificial intelligence in this case offers several insights for educational practice:

(i) *Collaborative Meaning-Making*: The "collaborative construction of meaning" between mentor and student suggests that intelligence emerges through dialogue rather than existing as a fixed property of individuals. This aligns with Cochran-Smith and Lytle's (2009) concept of "inquiry as stance," where learning becomes a joint investigative process.

(ii) *Contextual Sensitivity*: The integration of local knowledge with sophisticated mathematical modeling demonstrates how different forms of intelligence can be synergistic rather than competing. This supports Shulman's (1986) understanding of pedagogical content knowledge as inherently contextual.

(iii) *Technological Mediation*: Rather than replacing human intelligence, computational tools served as mediating artifacts that expanded the student's capacity to engage with complex problems. This productive relationship suggests possibilities for AI integration that enhance rather than diminish human agency.

The case study suggests that the dichotomy between relational and artificial intelligence may be less productive than exploring their potential synthesis. The student's journey from resistance to mastery involved both sophisticated computational tools and deeply relational mentoring processes. Neither alone would have been sufficient.

This synthesis challenges us to reconsider what we mean by intelligence in educational contexts. Perhaps intelligence is not a possession of individuals or machines but an emergent property of relationships – between mentor and student, between local and global knowledge, between human intuition and computational power, between theoretical frameworks and lived experience.

The "confident presentation" and "conceptual mastery" achieved by the student represents not just individual achievement but the successful orchestration of multiple forms of intelligence in service of understanding and preserving an Amazonian species. In this light, the question is not whether relational or artificial intelligence is superior, but how they might be combined to address the complex challenges facing our world.

As we move forward in an era of rapid technological advancement, this case study offers a model for maintaining human agency while leveraging artificial intelligence capabilities. The key lies not in choosing between relational and artificial intelligence but in cultivating the wisdom to know how they might work together in service of learning, understanding, and ultimately, the flourishing of both human communities and the natural world they inhabit.

Undergraduate Thesis 2: Numerical Modeling of Vertical Thermal Stratification in Lake Tefé

The second study was titled "Numerical Modeling of Vertical Thermal Stratification in Lake Tefé" and focused on developing a computational model capable of representing the variation in water temperature at different depths over time. The primary objective was to understand thermal stratification patterns in an Amazonian aquatic ecosystem, with direct implications for nutrient dynamics, aquatic metabolism, and the life of species inhabiting the lake.

From a methodological perspective, the undergraduate thesis involved formulating a simplified partial differential equation, discretization via numerical methods (such as finite differences), and computational implementation in a suitable programming language (MATLAB). The student also had to address the scarcity of local experimental data, which required the use of estimated values based on scientific literature and historical temperature records when available.

During the advising process, the relational dimension played a central role in the project's development. The technical complexity of the algorithms and the abstract nature of the involved physical and mathematical concepts occasionally led to feelings of uncertainty in the student. These moments of vulnerability were not merely technical but emotional, revealing the need for relational support structures in navigating academic challenges. Attentive listening, constructive feedback, and the validation of small advances became core mentoring strategies that restored momentum and confidence.

Joint code analysis sessions were particularly effective, not only for resolving programming errors or numerical inconsistencies but also for enabling a dialogical space where questions could emerge organically. In these shared moments, the boundaries between teacher and learner blurred, giving way to a collaborative epistemic environment grounded in mutual respect and exploratory thinking.

Another relevant aspect was the alternation between technical guidance and discussions on the social and environmental relevance of the topic. By connecting the research problem to local issues – such as the influence of thermal stratification on water quality consumed by riverside communities or the behavior of aquatic species – the work regained meaning, and the student engaged in an ethical commitment to the region. This integration of cognition and affect was decisive in fostering perseverance amid challenges and reaffirmed the role of education as a practice of responsibility.

Although the direct use of artificial intelligence tools was not central to this thesis, the methodology employed aligns with advanced computational practices and was enriched by introducing AI elements in the analysis process. The student was encouraged to use AI-based resources to interpret and discuss the graphical outputs of the code, exploring simulated thermal patterns and formulating hypotheses about the lake's dynamics. This targeted incorporation of AI, albeit preliminary, represented a step forward in the student's analytical autonomy and fostered a more critical investigative stance, connected to emerging tools in higher education.

Throughout the supervision process, relational education supported the development of academic self-efficacy and resilience – psychological foundations that sustained the student's engagement and progression. These experiences echoed the theoretical frameworks of Goleman (1995), Freire (1996), and Vygotsky (1978), reinforcing the idea that emotional support, dialogical interaction, and scaffolded guidance are vital for transformative learning.

By the end of the advising process, the work was well received by the evaluation committee and signaled potential for continuity in scientific initiation and university extension projects. More than an academic product, the undergraduate thesis became a formative journey in which relational intelligence served as the foundation for critical thinking, autonomy, and meaningful knowledge appropriation.

The experience described in this undergraduate thesis on numerical modeling of thermal stratification in Lake Tefé opens a fertile space for reflection on the nature of intelligence(s) in contemporary educational contexts. The tension between relational and artificial intelligence, as evidenced in this mentoring process, invites us to examine how these different forms of intelligence can complement rather than compete with each other in higher education.

The centrality of the relational dimension observed in this thesis aligns with Goleman's (1995) seminal work on emotional intelligence, which emphasizes the importance of emotional awareness and interpersonal skills in learning processes. The mentoring relationship described here exemplifies what Goleman identifies as the core competencies of emotional intelligence: self-awareness (recognizing the student's feelings of uncertainty), empathy (understanding the student's struggles), and social skills (providing appropriate support and encouragement).

This relational approach resonates deeply with Freire's (1996) pedagogical philosophy, which views education as a dialogical process rather than a mere transmission of knowledge. The "attentive listening to expressed difficulties" mentioned in the thesis reflects Freire's concept of critical pedagogy, where the educator-student relationship is characterized by mutual respect and collaborative inquiry. The integration of technical guidance with discussions on social and environmental relevance exemplifies Freire's emphasis on connecting learning to lived experience and social transformation.

Vygotsky's (1978) concept of the ZPD provides another theoretical lens through which to understand the success of this mentoring approach. The "joint code analysis sessions" and "guided readings" described in the thesis represent precisely the kind of scaffolded learning that Vygotsky advocated, where the mentor's guidance helps the student achieve what would be impossible to accomplish independently. The emotional support provided during moments of uncertainty becomes crucial in maintaining the student within their ZPD, preventing frustration from derailing the learning process.

The preliminary incorporation of AI tools in this thesis, while limited, anticipates the transformative potential that Bond et al. (2023) identify in their meta-systematic review of AI in higher education. The authors' call for "increased ethics, collaboration, and rigour" in AI implementation finds practical expression in the careful and targeted use of AI resources for interpreting graphical outputs and formulating hypotheses about lake dynamics.

Zawacki-Richter et al. (2019) raise the crucial question: "where are the educators?" in AI research in higher education. The experience described in this thesis suggests an answer: educators remain central as mediators who determine when, how, and why AI tools are introduced into the learning process. The AI integration was not autonomous but carefully orchestrated within the relational framework of mentoring, suggesting that artificial intelligence becomes most powerful when embedded within relational intelligence.

The application of AI tools to analyze thermal patterns and generate hypotheses represents what Cavus (2010) describes as the potential of artificial intelligence fuzzy logic algorithms in educational evaluation systems. However, the thesis demonstrates that the value of these tools emerges not from their technical sophistication alone, but from their integration into a meaningful learning relationship where the student develops "analytical autonomy" and "critical investigative stance."

The experience described challenges the binary opposition often assumed between human and artificial intelligence. Instead, it suggests what might be called "hybrid intelligence" – a synergistic integration where relational and artificial forms of intelligence amplify each other's strengths while compensating for their respective limitations.

Maturana's (1990) work on emotions and language provides insight into this integration. The emotional dimension of learning – the student's feelings of uncertainty, the mentor's empathetic response, the renewed engagement through social relevance – cannot be replicated by AI. Yet AI tools can extend human cognitive capabilities in ways that enhance rather than replace the relational dimension. The student's use of AI to interpret thermal patterns freed cognitive resources for higher-order thinking and ethical reflection about the research's social implications.

This complementarity is further illuminated by Shulman's (1986) concept of pedagogical content knowledge. The mentor's role involved not just technical expertise in numerical modeling, but also knowledge of how to teach these concepts, when to provide support, and how to connect abstract mathematical concepts to meaningful environmental issues. This pedagogical intelligence remains fundamentally relational and contextual, requiring the kind of situated understanding that AI currently cannot provide.

The thesis experience offers several insights for the broader integration of AI in higher education. First, it suggests that AI tools are most effective when they serve to enhance rather than replace human relationships in learning. The preliminary use of AI in this thesis succeeded because it was embedded within a strong mentoring relationship that provided emotional support, contextual meaning, and an ethical framework. This aligns with findings from Guo et al. (2025), which emphasize the critical role of teacher emotional support in fostering student learning engagement. Their research shows that emotional support not only directly influences student motivation and involvement but also indirectly enhances engagement through the development of academic self-efficacy and academic resilience.

Second, the experience highlights the importance of educators cultivating conditions that enable these internal psychological resources to flourish. According to Guo et al., teacher emotional support plays a foundational role in helping students build confidence in their academic abilities (self-efficacy), which in turn strengthens their capacity to cope with challenges and setbacks (resilience). These two factors together create a powerful psychological foundation that sustains student engagement. In the context of integrating AI into education, this means that technology should be introduced in ways that reinforce – not undermine – the supportive and developmental role of the educator.

Third, the integration of cognitive and affective dimensions – connecting technical modeling to environmental and social concerns – suggests that effective AI integration must consider not just computational efficiency but also emotional engagement and ethical responsibility. This aligns with Zembylas's (2021) emphasis on the affective turn in education and the need to attend to emotional dimensions of learning.

The Lake Tefé thesis suggests possibilities for what might be termed "relational-artificial intelligence synthesis" in higher education. This approach would recognize that:

1. *Relational intelligence provides the foundation*: Emotional support, contextual meaning, and ethical framework remain fundamentally human contributions to learning.
2. *Artificial intelligence offers cognitive amplification*: AI tools can extend analytical capabilities, process complex data, and generate new hypotheses, but their value emerges through human interpretation and application.
3. *Integration requires pedagogical wisdom*: The decision of when, how, and why to incorporate AI tools requires sophisticated understanding of learning processes, student needs, and educational goals.
4. *Meaning emerges through relationship*: The student's engagement with both thermal modeling and AI tools gained significance through connection to local environmental issues and social concerns – connections that emerged through dialogue with the mentor.

This synthesis challenges both technological determinism (the idea that AI will inevitably transform education) and technological resistance (the rejection of AI as incompatible with humanistic education). Instead, it suggests that the future of higher education lies in thoughtful integration that preserves and enhances the relational dimensions of learning while leveraging the analytical capabilities of artificial intelligence.

The undergraduate thesis on Lake Tefé thermal stratification thus becomes more than a technical exercise – it becomes a case study in how relational and artificial intelligence can work together to create meaningful, transformative learning experiences that serve both individual development and social good. In this synthesis, intelligence is not singular but multiple, not competitive but complementary, not artificial or relational but both, in service of human flourishing and environmental understanding.

This case illustrates that even when AI plays a secondary role in technical modeling, its value is best realized when integrated within a robust relational framework. The student's ability to explore simulation outputs and construct hypotheses depended not only on technical competence but on a supportive educational environment that encouraged reflection, interpretation, and ethical connection to context.

Taken together, the two case studies presented in this article demonstrate how relational and artificial dimensions – when intentionally integrated – can foster both scientific advancement and human development in higher education.

Final Considerations

The supervision experiences presented in this article highlight the interplay between relational education and artificial intelligence in guiding undergraduate thesis projects within the Amazonian context. These two cases – focusing on fuzzy modeling of dolphin population and numerical simulations of thermal stratification – illustrate that while technical expertise and AI tools are essential, the success of such endeavors remains deeply rooted in relational practices such as trust, dialogue, active listening, and contextual sensitivity.

The findings reveal that the tension between technical dependence and human mediation is not merely theoretical – it plays out concretely in the mentoring process. Whether resisting fuzzy logic due to misconceptions about precision or navigating uncertainty in numerical simulations, students required relational scaffolding to reframe their epistemological assumptions and reclaim agency in their learning trajectories. Rather than suppress this tension, educators can embrace it as a pedagogical opportunity, fostering a reflective stance on the role of uncertainty, interpretation, and ethical judgment in scientific inquiry.

In both cases, knowledge was co-constructed through an iterative, dialogical process where mentor and student explored, revised, and contextualized models together. This horizontal approach to supervision enabled the development of epistemological autonomy and contributed to the emergence of critical, ethically engaged scientific identities. These experiences affirm that artificial intelligence can extend cognitive capacities, but must be mediated by human insight and pedagogical intentionality.

To further clarify how the integration of artificial and relational dimensions materialized in the two supervised projects, Table 1 presents a comparative overview. It highlights the convergence of ecological, mathematical, territorial, technological, and relational aspects, illustrating how each dimension contributed to shaping both the research process and the students' formative trajectories.

Looking ahead, these experiences underscore the importance of cultivating pedagogical wisdom to balance technological innovation with affective engagement. In socio-culturally diverse and geographically unique contexts like the Brazilian Amazon – where students may face additional educational and logistical barriers – the relational dimension becomes even more crucial in promoting inclusion, perseverance, and meaningful learning.

Table 1 – Synthesis of key dimensions in the research process

Dimension	**Thesis 1: Fuzzy control of dolphin population**	**Thesis 2: Thermal stratification modeling**
Ecological	Biodiversity preservation, climate impacts	Water temperature, aquatic life
Applied Mathematics	Fuzzy optimal control, ordinary differential equations	Partial differential equations, numerical methods, discretization
Territorial	Local knowledge from Iranduba	Water consumption by riverside communities
AI Integration	Fuzzy inference systems, computational simulations	AI-assisted graph interpretation, hypotheses formulation
Relational Education	Co-construction, epistemic reframing, emotional support	Dialogic guidance, resilience-building

Moreover, the implications of relational approaches for research education extend beyond emotional support. They inform how research questions are framed, how data is interpreted, and how ethical responsibility is assumed. By centering relationships as epistemic sites, supervision becomes not only a site of transmission but also of transformation – where the learner's voice, identity, and agency are actively shaped.

The future of pedagogy lies not in choosing between AI and relational education, but in cultivating the discernment to integrate them with care and purpose. When aligned, these forms of intelligence foster rigorous inquiry, resilient learning, and socially responsive knowledge production – capacities urgently needed to address the complex challenges of our interconnected world.

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