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The Pedagogical Power of Quantum Metaphors: Rethinking the Student as a Contextual Being

Kuantum Metaforlarının Pedagojik Gücü: Öğrenciyi Bağlamsal Bir Varlık Olarak Yeniden Düşünmek

Ayhan Aksakallı[1]

[1] Assoc. Prof. Dr., Bayburt University, School of Health Services, Bayburt, Türkiye

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Ayhan Aksakallı

Bayburt Üniversitesi, Sağlık Hizmetleri Meslek Yüksekokulu, 69000, Merkez, Bayburt

ayhanaksakalli@bayburt.edu.tr

Abstract: This study examines how quantum metaphors such as wave-particle duality, observer effect, uncertainty principle, and superposition reframe the ontology of the learner in educational contexts. Using interpretative phenomenological analysis, the research explores how fifteen undergraduate physics students perceive their learning experiences through these metaphors. Findings reveal that learners do not possess fixed, measurable identities. Instead, they emerge as fluid, relational beings whose subjectivities are continuously shaped by contextual interactions. Wave-particle duality highlights the fragile multiplicity of student identity, while the observer effect shows how pedagogical environments reconstruct self-perception through observation. The uncertainty principle reflects students' epistemological disorientation and ontological instability, and superposition reveals the coexistence of conflicting roles and desires. The study critiques traditional assessment practices that reduce learners to standardized outcomes, advocating for formative and process-centered evaluations that acknowledge complexity and becoming. Through the notion of quantum pedagogy, the research proposes a dynamic, observer-dependent understanding of learner subjectivity. Ultimately, quantum metaphors are positioned not merely as explanatory devices but as critical tools for reimagining pedagogical existence, offering a framework attuned to the complexities of contemporary education.

Keywords: Contextual learning, educational ontology, pedagogical subjectivity, quantum metaphors, student identity

Öz: Bu çalışma, kuantum metaforlarının -dalga-parçacık ikiliği, gözlemci etkisi, belirsizlik ilkesi ve süperpozisyon- eğitim bağlamlarında öğrenenin ontolojisini nasıl çerçevelediğini incelemektedir. Araştırma, yorumlayıcı fenomenolojik analiz kullanarak, on beş lisans fizik öğrencisinin öğrenme deneyimlerini bu metaforlar aracılığıyla nasıl algıladıklarını incelemektedir. Bulgular, öğrenenlerin sabit, ölçülebilir kimliklere sahip olmadıklarını ortaya koymaktadır. Bunun yerine, öznellikleri sürekli olarak bağlamsal etkileşimlerle şekillenen akışkan, ilişkisel varlıklar olarak ortaya çıkmaktadırlar. Dalga-parçacık ikiliği öğrenci kimliğinin kırılgan çokluğunu vurgularken, gözlemci etkisi pedagojik ortamların gözlem yoluyla benlik algısını nasıl yeniden yapılandırdığını göstermektedir. Belirsizlik ilkesi öğrencilerin epistemolojik yönelim bozukluğunu ve ontolojik istikrarsızlığını yansıtırken, süperpozisyon ise çatışan rollerin ve arzuların bir arada var olduğunu ortaya koymaktadır. Çalışma, öğrencileri standartlaştırılmış sonuçlara indirgeyen geleneksel değerlendirme uygulamalarını eleştirmekte, karmaşıklığı ve oluşu kabul eden biçimlendirici ve süreç merkezli değerlendirmeleri savunmaktadır. Kuantum pedagojisi kavramı aracılığıyla araştırma, öğrenen öznelliğine ilişkin dinamik, gözlemciye bağlı bir anlayış önermektedir. Sonuç olarak, kuantum metaforları yalnızca açıklayıcı araçlar olarak değil, pedagojik varoluşun yeniden tasarlanması için kritik araçlar olarak konumlandırılmakta ve çağdaş eğitimin karmaşıklıklarına uygun bir çerçeve sunmaktadır.

Anahtar Kelimeler: Bağlamsal öğrenme, eğitimsel ontoloji, pedagojik öznellik, kuantum metaforları, öğrenci kimliği

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Introduction

In recent years, metaphors derived from quantum physics have increasingly found theoretical resonance in educational research, offering new ways to conceptualize the complexity of learning and identity formation (Davis, 2004; Rodriguez et al., 2024). In contrast to traditional educational paradigms that view the learner as a fixed and measurable entity, quantum metaphors emphasize fluidity, contextual responsiveness and ontological multiplicity. This orientation necessitates rethinking the learner not as a fixed subject of performance but as a dynamic entity intertwined with context (Mitchell et al., 2016). This transformation is not merely a linguistic move; it is an attempt to radically transform how the phenomenon of education itself is conceptualized (Barad, 2007). Seen through this lens, quantum metaphors not only enrich pedagogical language but also profoundly challenge established notions of identity, learning and achievement. For instance, in physics, "wave-particle duality" refers to the phenomenon where light and matter can behave both as particles and as waves depending on how they are observed; in education, this can be likened to students demonstrating different abilities depending on the context and method of evaluation. Similarly, the 'observer effect' in quantum mechanics, where the act of observation alters the state of a system, parallels the way teacher expectations or classroom assessments can influence student performance. The 'uncertainty principle,' which states that certain properties cannot be precisely measured at the same time, reflects the idea that learning outcomes are not always fully predictable, while 'superposition' in quantum physics, being in multiple states at once, mirrors the possibility of students holding multiple, sometimes conflicting, understandings during complex learning processes.

Classical education systems, strongly influenced by positivist epistemologies, tend to reduce the learner to measurable outcomes such as grades, exam results and behavioral assessments (Biesta, 2010; Pinar, 2012). In these systems, success is often defined through external validation mechanisms, which renders the relational, contextual and emergent dimensions of learning invisible (Elliott, 2012). As Biesta (2013) argues, such approaches overlook the inherently unpredictable and risky nature of education, where genuine learning often emerges beyond standardized metrics and predetermined outcomes. These measurement-centered approaches alienate students from learning processes and relegate them to the position of passive recipients of predefined knowledge structures rather than the collaborative

construction of meaning (Priestley, 2011). Overcoming this instrumentalizing view necessitates the development of alternative ontologies that place elements such as complexity, uncertainty and emergence at the center of the educational experience.

Alongside this, quantum metaphors such as superposition, entanglement, and the observer effect challenge the binary patterns of thought, such as success/failure, knowledge/ignorance, and competence/incompetence, that are often embedded within educational practices (Barad, 2007, 2012; Fenwick, 2010). These metaphors invite us to view learning not as a fixed and definite event but as an uncertain and relational process in which identity, knowledge, and subjectivity are continually reconstructed through contextual interactions. The idea that knowledge is not a static object but an event that simultaneously transforms both the learner and the learning environment comes to the fore (Gough, 2012). This perspective emphasizes that epistemology and ontology cannot be separated; what and how we know is always entangled with who we are (Barad, 2007; St. Pierre, 2013).

In light of these considerations, this study aims to explore how quantum metaphors offer a conceptual framework for rethinking the pedagogical existence of students. The research question is formulated as follows:

"How do quantum metaphors provide conceptual depth for understanding the pedagogical being of the student?"

This question is not merely a theoretical inquiry; it carries direct practical implications for curriculum design, assessment practices, and pedagogical relationships. Engaging with quantum metaphors invites educators to create pedagogical spaces that honor uncertainty, relationality, and multiplicity, while critically resisting the tendencies toward closure, standardization, and uniformity (Taylor, 2016).

Based on a thematic analysis of four key quantum metaphors, wave-particle duality, observer effect, uncertainty principle, and superposition, this study seeks to reconceptualize instability, multiplicity, and contextual entanglement as foundational elements of educational subjectivity.

Beyond its theoretical scope, this study holds significant importance for both educational theory and practice. While previous research has applied quantum metaphors in limited or abstract ways, often focusing on conceptual analogies without exploring their pedagogical implications in depth (e.g., Fenwick, 2010; Saban, 2006; Sfard, 1998; Taylor, 2004), the present study directly investigates how such metaphors can reframe the ontology of the learner within real educational contexts.

By integrating wave-particle duality, the observer effect, uncertainty principle, and superposition into an interpretative phenomenological framework, the research seeks to enrich the conceptual vocabulary of educational discourse while also providing empirical insights into how these metaphors resonate with students' lived experiences. This contribution, linking theoretical debates on learner subjectivity with practical considerations for curriculum design and assessment, aims to position the study as a bridge between abstract philosophical models and pedagogical practices. In doing so, it contributes to ongoing discussions on the need for alternative ontologies that can address the complexities of contemporary education, where stability and certainty are often elusive.

Accordingly, this paper first conceptualizes the four main quantum metaphors—wave-particle duality, observer effect, uncertainty principle, and superposition—in relation to student identity and learning processes; then presents thematic analysis findings structured around these metaphors; and finally concludes with a discussion aimed at rethinking the pedagogical existence of the student through the lens of quantum ontology.

Theoretical Background

Quantum physics has profoundly challenged classical understandings of reality and has offered conceptual tools with increasing influence beyond the natural sciences. Fundamental principles such as wave-particle duality, the observer effect, the uncertainty principle, and superposition disrupt the notion of a stable, objective world, foregrounding instead uncertainty, relationality, and multiplicity (Barad, 2007; Bohr, 1958). For instance, wave-particle duality undermines the idea that being carries intrinsic properties, proposing instead that existence is contingent upon observation and measurement (Bohr, 1958). Similarly, the observer effect reveals that the act of measurement is not neutral but plays a constitutive role in the formation of reality (Heisenberg, 1958). These quantum principles expose an ontological and epistemological instability that stands in stark contrast to the Cartesian model of the autonomous subject. Quantum thought suggests that the subject is not an isolated knower detached from the world but a being fundamentally entangled with material, social, and discursive environments (Barad, 2007; Stengers, 2010).

This epistemological shift carries profound implications for traditional educational models, which assume that learners acquire knowledge as separate, objective facts. The incorporation of metaphor into educational theory has further destabilized these assumptions. Since the pioneering work of Lakoff and Johnson (2003), metaphors are no longer viewed merely as figures of speech but as fundamental tools for human cognition and meaning-making. In educational contexts, metaphors serve not only as explanatory devices but also as generative mechanisms that shape learners' understandings of knowledge, identity, and agency (Sfard, 1998; Taylor, 2004). Rather than producing definitive closures, metaphors open new domains of meaning, encouraging learners to inhabit worlds of possibility, uncertainty, and relationality (Fenwick & Edwards, 2012; Saban, 2006).

At the intersection of quantum thought and educational metaphor, the notion of contextually constructed learner identity emerges with particular force. Theories of contextual pedagogy emphasize that learner subjectivity is not pre-given but dynamically formed through interactions with social, material, and symbolic environments (Biesta, 2004; Foucault, 1982; Luhmann, 1996). Foucault's (1982) conceptualization of the "subject" challenges the autonomous learner model and foregrounds the relational and fragile nature of educational identities. Similarly, Biesta (2004) argues that education should not aim to produce fixed competencies but should support the emergence of singular and contextually responsive subjects. Luhmann's (1996) systems theory conceptualizes learning as an autopoietic process in which meaning is not transmitted but self-produced within complex and contingent systems. Within this framework, the student appears as a being-in-becoming, continually shaped by the flows of interactions, observations, and uncertainties.

Within this theoretical landscape, quantum metaphors do not function merely as decorative language; rather, they operate as critical tools for rethinking the ontology of the learner. These metaphors question reductionist, measurement-centered paradigms and invite educational theorists and

practitioners to confront the multiplicity, uncertainty, and contextual entanglement that constitute the very foundations of learning and subject formation.

Despite the growing interest in quantum metaphors within educational discourse, much of the existing scholarship remains either abstract, focusing on theoretical parallels without empirical grounding, or limited to isolated classroom strategies. Few studies have explicitly examined how these metaphors can be systematically integrated into an interpretative phenomenological framework to reconceptualize the student as a contextually entangled pedagogical being. This gap is particularly significant because it leaves underexplored the ways in which quantum metaphors might bridge philosophical theory and lived educational experience. Addressing this lacuna, the present study seeks to operationalize four central quantum metaphors, wave-particle duality, observer effect, uncertainty principle, and superposition, not merely as analogies but as conceptual lenses capable of reshaping both the ontology of the learner and the design of pedagogical practices.

Methodology

Research Design

This study was conducted to examine how four fundamental concepts of quantum physics, wave-particle duality, observer effect, uncertainty principle, and superposition, are metaphorically conceptualized within the context of education. The research conceptualizes the student not merely as an individual who acquires knowledge, but as a pedagogical being shaped by context and invested with subjective experiences. Accordingly, the study was structured based on a qualitative research approach.

The method adopted in this study is the Interpretative Phenomenological Analysis (IPA) model. IPA is a methodology designed to reveal individuals' subjective meanings related to a particular lived experience and is particularly effective in studies that aim to understand an individual's internal world, contextual perceptions, and emotional responses in depth (Smith et al., 2009).

Within this framework, IPA not only describes students' narratives but also allows an interpretation of how students construct their learning processes, identity formation, and pedagogical positioning through quantum metaphors. This methodological choice theoretically and methodologically serves the study's primary aim: to explore the pedagogical power of quantum metaphors and to rethink the student as a contextual being.

Study Group

The study group of this research consists of a total of 15 undergraduate students enrolled in the physics program of a public university in Turkey during the 2024–2025 academic year. In line with Patton's (2015) definition, purposive sampling was employed to deliberately select participants who could provide rich, relevant, and in-depth information about the phenomenon under investigation. According to Patton, purposive sampling is particularly appropriate when the goal is to gain deep insights from information-rich cases rather than to achieve statistical generalization. For this reason, participants were intentionally chosen among students who had substantial exposure to quantum physics courses, ensuring that they possessed both the conceptual background and reflective capacity to offer meaningful and detailed accounts of their learning experiences. The group was intentionally kept homogeneous in terms of academic discipline and course background, comprising only physics majors who had completed or were taking core quantum physics courses, in order to ensure a shared conceptual foundation. This homogeneity allowed for comparability of responses while focusing the analysis on variations in subjective interpretations rather than differences in disciplinary knowledge (Patton, 2015).

To ensure diversity, attention was paid to balancing participants' gender, class level, and quantum course background (whether participants had completed or were currently enrolled in core quantum physics courses). All participants volunteered to take part in the study, were informed about the research procedures prior to participation, and signed informed consent forms. Anonymity and confidentiality of participant information were rigorously maintained throughout the study. In addition, ethical approval for this research was obtained from the Ethics Committee of Bayburt University, with Decision Date: 07.05.2025, Decision Number: 199, and Session Number: 5. Accordingly, the demographic information and basic characteristics of the participating undergraduate physics students are summarized below in Table 1.

Table 1. Participant profile

Participant ID	Gender	Year level	Quantum course taken
P1	Female	3rd Year	Yes
P2	Male	4th Year	Yes
P3	Female	3rd Year	Yes
P4	Male	3rd Year	Yes
P5	Male	3rd Year	Yes
P6	Male	4th Year	Yes
P7	Female	4th Year	Yes
P8	Female	3rd Year	Yes
P9	Male	3rd Year	Yes
P10	Female	4th Year	Yes
P11	Female	4th Year	Yes
P12	Male	3rd Year	Yes
P13	Male	4th Year	Yes
P14	Female	3rd Year	Yes
P15	Male	3rd Year	Yes

Data Collection Tools

In this study, data were collected through semi-structured individual interviews. The interview form consisted of open-ended questions designed to deeply explore how students perceive four fundamental concepts of quantum physics, wave-particle duality, observer effect, uncertainty principle, and superposition, as educational metaphors. The development of the interview questions followed a systematic process aligned with the study's theoretical framework and research questions. The interview questions were constructed in line with the theoretical framework of the study; they were developed to ensure conceptual clarity, to allow students to share their subjective experiences, and to facilitate their connection with the proposed metaphors (see Appendix 1). First, each of the four target metaphors was operationalized into specific conceptual dimensions (e.g., identity fluidity for wave-particle duality, performativity under observation for the observer effect), which served as focal points for question design. Second, draft questions were prepared to address these

focal dimensions at both cognitive and experiential levels, ensuring that each question prompted participants to reflect not only on conceptual understanding but also on personal and pedagogical experiences. Third, the draft questions were reviewed by two experts in physics education and one expert in qualitative research to assess clarity, relevance, and depth, and were revised based on their feedback. This process ensured that the questions were neither too broad to lose focus nor too narrow to limit participant expression, thereby maintaining an optimal focus intensity for Interpretative Phenomenological Analysis (IPA). To establish content validity, the draft interview form was subjected to expert review by three specialists: two professors in physics education with over 15 years of teaching and research experience in quantum physics pedagogy, and one associate professor in educational sciences specializing in qualitative research methodologies. Each expert was provided with the initial version of the interview form, the operational definitions of the targeted metaphors, and the study's theoretical framework. They evaluated the form for conceptual accuracy, clarity of wording, and alignment with the research questions. Their feedback was systematically categorized into suggestions for rewording, restructuring, and enhancing metaphorical prompts. Inter-rater agreement was sought for critical revisions, and a consensus process was followed until all experts confirmed the adequacy of the items. To ensure reliability, the form was piloted with two physics students who met the study's selection criteria but were not part of the main sample. The pilot data were analyzed to check the consistency of responses and the interpretability of questions, leading to minor refinements before the main data collection. To make the structure of the data collection tool more transparent, illustrative examples of the interview questions were included in the study protocol. For instance, one question asked, *"When thinking about wave–particle duality, how do you relate the idea of a learner having multiple potentials to your own educational experience?"* Another prompt was, *"In your view, how does the observer effect relate to how you perform or change when you know you are being assessed in a classroom?"* A further example invited participants to consider, *"How might the uncertainty principle be connected to the unpredictability of your own learning process?"* These examples demonstrate how the quantum concepts were operationalized into prompts that encouraged participants to connect theoretical understanding with personal and pedagogical reflections.

All interviews were audio-recorded with the consent of the participants, and the entire process was conducted in accordance with ethical guidelines. Participation was voluntary, and measures were taken to anonymize the data and ensure the confidentiality of personal information.

Data Collection Process

The data for this study were collected primarily through semi-structured individual interviews, which were designed to capture participants' in-depth reflections and subjective interpretations regarding the research topic. This study investigated how fundamental concepts of quantum physics are reflected metaphorically in students' learning experiences. Since the study aims to reconceptualize the student not merely as a knowledge-acquiring subject but as a pedagogical being shaped by context and transformed through observation, the data collection process was structured to reflect this ontological framework. The process was conducted in three main stages: participant selection, a conceptual preparation session, and semi-structured individual interviews.

The data collection process began with a conceptual preparation session conducted prior to the interviews. During this 75-minute session, four fundamental concepts of quantum physics, wave-particle duality, observer effect, uncertainty principle, and superposition, were presented to students in a clear and accessible manner. Subsequently, discussions were held on how these concepts could function as educational metaphors. For example, the "wave-particle duality" metaphor was framed to represent the varying behaviors of students across different learning environments, while the "observer effect" was introduced as a metaphor for how the presence of the teacher or the system could transform a student's subjective performance. Given that the metaphors central to the research topic were explicitly introduced and exemplified before data collection, there was an awareness of the potential 'priming effect,' whereby participants' spontaneous and self-generated associations with the metaphors might be constrained. In recognition of this risk, particularly relevant for an IPA approach aiming to uncover the participant's subjective meaning-making, care was taken to encourage students to explore personal and idiosyncratic interpretations beyond the examples provided, and to avoid framing the metaphors in a way that would predetermine or narrow their responses.

In acknowledging that the study incorporated both small-group discussions and individual interviews, there was an awareness of the potential for "social interaction bias," whereby participants might develop shared discourses or align their views through peer influence. This is particularly relevant in the context of IPA, which focuses on the individuality of lived experiences and is generally cautious about group formats even for preliminary data. To mitigate this risk, the group activity was explicitly framed as a pre-interview reflective exercise rather than a co-constructive meaning-making session. Students were reminded that their forthcoming individual interviews were the primary focus of the study and that their personal, unique, and potentially divergent perspectives were of the highest value. Furthermore, prompts during the group discussions were intentionally designed to remain open-ended and non-directive, reducing the likelihood of converging toward a collective narrative.

In the second part of the session, students were divided into small groups of three, and each group was assigned one quantum metaphor. They were asked to engage in short discussions around the question: "What might this metaphor represent in your educational life?" These group discussions encouraged students to connect with the metaphors not only cognitively but also experientially and emotionally. At the end of the session, each student was asked to individually write down which metaphor they felt most connected to and why. These individual narratives served as preliminary insights for the subsequent interview process and as important records of the students' initial conceptual positioning.

The final stage of data collection consisted of semi-structured individual interviews conducted with each participant. Interviews were conducted either face-to-face or online, each lasting approximately 45 to 60 minutes. With participants' consent, all interviews were audio-recorded and later transcribed. The open-ended questions included in the interview form aimed to explore how students related personally, pedagogically, and cognitively to the four quantum metaphors. This approach provided students with an opportunity not only to articulate their processes of knowledge

acquisition but also to express how they constructed their relationships with teachers, their experiences of examinations, their emotional positioning within learning environments, and their broader subjective learning identities.

Data Analysis Techniques

The qualitative data in this study were analyzed using (IPA), which is specifically designed to explore in depth how individuals make sense of their lived experiences (Smith et al., 2009). In line with IPA's idiographic and interpretative orientation, the analysis process focused on preserving the individuality of each participant's meaning-making while also identifying points of convergence across cases.

The analysis followed the sequential steps recommended in IPA methodology:

1. Reading and re-reading each transcript to achieve deep familiarity with the participant's account.
2. Making detailed initial notes on descriptive content, linguistic features, and preliminary conceptual interpretations.
3. Transforming these exploratory notes into emergent themes that capture the psychological essence of the participant's meaning.
4. Searching for connections across emergent themes within each case and clustering them into superordinate themes.
5. Repeating the process for each new case while bracketing prior interpretations to maintain an idiographic focus.
6. Identifying patterns across cases, noting both shared themes and individual divergences, and refining the thematic structure accordingly.

All interviews were transcribed verbatim by the researcher, and each participant was assigned an anonymized code (e.g., P1, P2) to ensure confidentiality. The coding process was carried out manually, and the interpretative dimension of IPA was maintained through a double hermeneutic approach, whereby the researcher sought to make sense of how participants made sense of their own experiences.

To ensure validity and credibility, addressing the first reviewer's emphasis, multiple strategies were incorporated: peer debriefing with two qualitative research experts to review coding and theme construction; constant comparison between emerging themes and raw data to prevent interpretative drift; and participant validation (member checking) by sharing preliminary interpretations with selected participants for feedback. These measures verified that the themes accurately reflected participants' intended meanings while strengthening the trustworthiness of the findings.

Findings

This section presents the analysis of the data obtained through in-depth interviews conducted with undergraduate students from the physics department. The analysis process aimed to reveal how participants conceptualized four fundamental quantum physics concepts, wave-particle duality, observer effect, uncertainty principle, and superposition, through educational metaphors. These concepts were treated not merely as physical notions but also as metaphorical structures representing students' learning processes, identity formation, and assessment experiences.

In line with the thematic analysis, the findings were structured around each quantum metaphor separately, with each theme supported by distinctive codes and participants' narratives. As students' ways of expressing their subjective experiences gained meaning through the metaphors, these themes were also evaluated as pedagogical interpretative grounds. In this context, metaphors functioned not only as conceptual explanatory tools but also as mechanisms for meaning-making that revealed how students positioned themselves within educational environments and how they made sense of their existence within these contexts. All findings presented in this section are derived solely from the semi-structured individual interviews. The small-group reflective activity conducted prior to the interviews served only as a preparatory exercise, enabling participants to formulate their initial personal connections with the quantum metaphors. The written reflections produced in this activity were not analyzed as a separate dataset but were used exclusively to inform and contextualize the subsequent interview process.

Furthermore, each metaphorical theme was supported not only through textual analysis but also through visually structured diagrams (e.g., Figure 1, Figure 2). These visuals were designed to expose the pedagogical and ontological meanings embedded in the metaphors, both theoretically and intuitively, and were presented at the end of each theme. In doing so, the findings were reconstructed not only on a content-based but also on a visual-epistemological level.

According to Table 2, the wave-particle duality metaphor provides a strong conceptual foundation for understanding that the behaviors students exhibit during their learning processes are not fixed but contextually shaped. Narratives highlighted in the interviews reveal that students experience their presence in educational environments not as a manifestation of a fixed identity but as a continuously shifting and reconstructed structure. This dynamic is closer to the uncertain and multiple subjectivities proposed by quantum theory than to the Cartesian model of the subject.

Table 2. Thematic findings on the wave-particle duality metaphor

Theme	Subtheme	Code	Frequency	Participant Description
Contextual Learning Experience	Variation According to Learning Environment	Individual vs group difference	5	**P2:** 'I'm very clear when I study alone, but I expand in class discussions. Like light.'
	Changing Role Based on Assessment Type	oral success, written struggle	4	**P7:** 'I struggle in exams but explain well in class. It's like I'm two people.'
Fluid Identity in Learning	Rejection of Singular Success Definition	Success is not fixed	6	**P11:** 'I'm not just exam success. Sometimes I write well, sometimes I talk well.'
	Variation According to Learning Environment	Learning style changes with context	5	**P5:** 'Sometimes I'm active, sometimes reserved. It depends on the environment.'
	Rejection of Singular Success Definition	Identity is not stable	7	**P8:** 'I don't always respond the same. The context and people affect me.'

For instance, P2's statement "When I study at home, I feel very focused, but in the classroom, I disperse. I feel like light." illustrates not merely a change in behavior across different contexts, but a fundamental transformation of being itself depending on the environment. Here, the student does not merely act differently; they become a different "self." This expression represents the student's capacity to diffuse like a wave and to exist relationally rather than individually.

Similarly, P7's remark, "I struggle during exams but feel comfortable when explaining in class," demonstrates how classical assessment practices in education constrain the student's potential. In this context, the exam functions as a rigid and sharp measurement tool, like a particle, whereas in-class expression enables a more expansive, wave-like performance. The student experiences an epistemological existence caught between these two contexts.

P11's statement captures a subjectivity that is aware of this tension: "I am not just my exam performance. Sometimes I write well, sometimes I speak well." This sentence carries a critique of how education traps the subject within one-dimensional success categories. The student's expression demands not only to move beyond the system but also to recognize their own subjective multiplicity.

Importantly, the frequency of codes in Table 2 provides further insights into these dynamics. High-frequency codes such as "identity is not stable" (7) and "success is not fixed" (6) indicate a widespread student experience of ontological fluidity and resistance to reductionist identity frameworks. These frequencies suggest that the tension between wave-like multiplicity and particle-like fixity is not an isolated phenomenon but a structural characteristic of contemporary pedagogical subjectivation.

Equally significant are lower-frequency codes like "oral success, written struggle" (4) and "learning style changes with context" (5). Though less prevalent numerically, these codes illuminate critical fracture points where students' experiences diverge from institutional expectations. The fact that students report performing well in oral contexts while struggling in written assessments reveals the limitations of standardized measurement tools, which privilege certain modalities of expression while marginalizing others. These marginal but resonant narratives underscore the necessity of pedagogical approaches that accommodate diverse, context-dependent manifestations of learning.

This analysis reveals that wave-particle duality is not merely a physical phenomenon but a metaphorical expression of the existential fragility and multiplicity that students experience in learning processes. The student is neither solely a wave nor merely a particle; rather, they are a subject transformed through observation, shaped by context, and constrained by the system. In this sense, the wave-particle metaphor is far more than a pedagogical concept: it serves as a conceptual gateway inviting a rethinking of the contemporary ontology of the learning subject.

To visually conceptualize how this multiplicity is pedagogically configured, Figure 1, "The Contextual Ontology of the Student," depicts the student as a relational entity, oscillating between wave and particle states in response to environmental, observational, and systemic forces. This figure not only illustrates the dynamic formation of subjectivity but also critiques the educational apparatuses that seek to stabilize and fix what is inherently fluid and emergent.

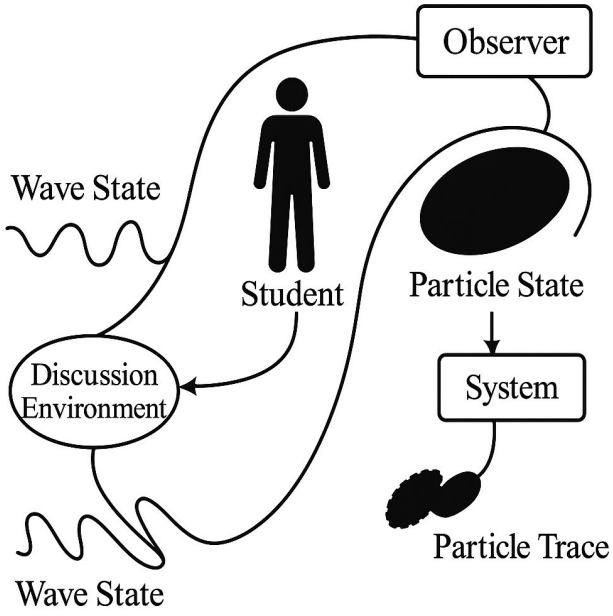

Figure 1. The contextual ontology of the student (Created using Microsoft PowerPoint)

Figure 1 represents the student's existence not as a fixed entity but as a structure that collapses through observation, changes through context, and is constrained by the system. Rather than being a passive object of knowledge, the student emerges as an unstable subjectivity, continuously shaped by pedagogical interactions. The wave symbolizes the student's capacity for multiple meanings, while the particle signifies the system's effort to singularize the learner. This diagram functions as a conceptual bridge, moving from a physical model to an ontological reorientation of pedagogical identity.

At the same time, this figure makes visible the transformative impact of educational assessment practices on the subject. Under the pressure of examinations, observations, and performance expectations, the student is reduced to a particle, whereas the wave-state, embodying potential multiplicity, intuitive knowledge, and contextual thinking, is progressively marginalized. Thus, the figure operates not merely as a quantum metaphor but as a critique of the normative construction of subjectivity within education.

The findings obtained from Table 2 support Barad's (2007) concept of quantum ontology, which emphasizes that entities are resolved through observation and context. The student is not a fixed subject but an emergent being that fluidly exists between wave and particle states within pedagogical environments. This also aligns with Biesta's (2010) emphasis on the "emergence of subjectivity" rather than the production of stable competencies.

While the wave-particle duality makes visible the contextual transformation of student identity, it is in dialogue with the observer effect metaphor, which reveals how external forces actively constrain and direct this transformation.

According to Table 3, the observer effect metaphor reveals that students are not merely individuals reaching knowledge but beings shaped by the very nature of observation. The students' narratives clearly illustrate how the subject can transform, be suppressed, or be forced into role-playing during the learning moment.

Table 3. Thematic findings related to the observer effect metaphor

Theme	Subtheme	Code	Frequency	Participant Description
Transformative Effect of Observation	Behavioral Change with Teacher Presence	I'm more careful when the teacher is in class	9	**P3:** 'When the teacher is in the room, I act like I'm always being graded.'
	Suppression of Spontaneity	I can't act naturally, I perform when observed	6	**P12:** 'I can't be natural, the moment I'm observed, it's like I start performing.'
Pressure on Performance	Observation Based on Exams and Grades	Being watched during exams freezes me	7	**P5:** 'If someone stands behind me in an exam, I go blank.'
	Fear of Being Observed	Being watched makes me nervous	8	**P6:** 'When someone watches me, I panic and forget everything.'
	Identification with a Sense of Inadequacy	I keep thinking they'll see me as a failure	4	**P10:** 'I always feel like people expect me to fail.'
Conflict of Self-Perception	Tension Between Inner and Outer Observation	I feel like I'm watching myself from outside	5	**P8:** 'Sometimes I feel like I'm outside my body watching myself, it's strange.'
	Mismatch Between Observed and Felt Self	Who I seem to be and who I feel I am don't match	6	**P14:** 'How I look and how I feel inside are totally different.'

Data categorized under the theme of "The Transformative Effect of Observation" show that students' behaviors change the moment they are observed by the teacher in the classroom. For instance, P3's statement, "When the teacher is in class, I act as if I'm constantly being graded," reflects not only a fear of surveillance but also indicates that the student's very presence is transformed into a performance under observation. Similarly, P12's remark, "I cannot be natural when observed; a role begins inside me," reveals how the student's spontaneity is suppressed and their authentic existence succumbs to the pressures of observation within the learning environment.

The theme of "Pressure on Performance" makes visible the tension experienced by students when observation is converted into measurement and evaluation. P5's expression, "When someone stands behind me during an exam, the words just disappear from my mind," describes not just exam anxiety but an epistemological collapse. In such moments, the student does not merely lose knowledge but loses a sense of self. P10's statement, "It feels like people are expecting me to fail," shows how students internalize the devaluation imposed by the system. This theme reveals how student identity becomes encircled by external criteria and how self-confidence is shaped through systemic observation.

The third theme, "The Conflict of Self-Perception," points to a rupture between the internal and external self. P14's words, "Inside, I feel different, but outwardly, I appear as someone else," illustrate how student identity splits between what is observable and what is felt. This contradiction signifies not just a pedagogical problem but an ontological rupture in the integrity of the learning subject. P8's comment, "Sometimes I feel like I am looking at myself from the outside," shows that the student experiences even their own existence from an alienated perspective, losing inner cohesion under the gaze of observation.

Importantly, the frequency analysis in Table 3 offers critical insights into how pervasive these experiences of observation-induced transformation are. High-frequency codes such as "behavioral change with teacher presence" (9) and "fear of being observed" (8) reveal that the observer effect is not a marginal phenomenon but a central mechanism through which educational subjectivity is constructed. These frequencies indicate that students consistently experience a shift from authentic self-expression to performative compliance when under observation, supporting the metaphor's ontological implications.

Equally noteworthy are codes with relatively lower frequencies, such as "identification with a sense of inadequacy" (4) and "tension between inner and outer observation" (5). Though less dominant numerically, these codes expose the deeper, often unspoken internal conflicts students face. The low frequency does not signify insignificance; rather, it highlights the subtle but profound psychological and existential fractures that occur when students are subjected to constant evaluative gazes. These narratives bring forward the nuanced ways in which observation shapes not only behavior but also self-perception and emotional resilience. This analysis demonstrates that the observer effect is not merely a matter of teacher control or evaluation but constitutes an existential mode of intervention. Here, the student is not a passive object of observation; rather, they become a pedagogical subject shaped, conflicted, and suppressed through observation. In this context, the observer effect metaphor functions as an invisible yet profound ontological force at the heart of the learning process. This multilayered pedagogical transformation reshapes the student's relationship with observation not only behaviorally but also ontologically.

To further conceptualize this process, Figure 2 visually represents the student's pedagogical transformation under observation. The diagram captures the tension between the student's inner sense of self and the performative identity imposed by the observer's gaze. By illustrating how observation collapses the student's potential into narrow evaluative frames, Figure 2 underscores the critical role of the observer effect as a structuring force in educational subjectivation. It reveals not only behavioral shifts but also the ontological reduction of the learner from a fluid, relational being into a measurable, performative entity.

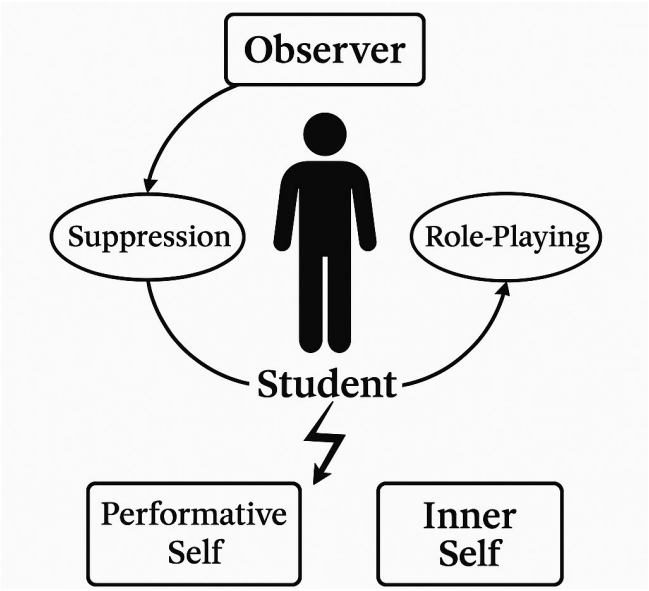

Figure 2. The pedagogical transformation of the student in the context of the observer effect (Created using Microsoft PowerPoint)

Figure 2 conceptually illustrates how the student's existence under observation is pedagogically transformed. Under the influence of the observing actor, whether the teacher, the examination, or the system, the student moves away from a natural state of learning and is directed toward a performance-based identity. This shift produces a conflicted space where the student navigates between internal self-perception and externally imposed appearances. Particularly, narratives around 'role-playing,' 'anxiety of being observed,' and 'self-conflict' make visible the tension at the center of this figure. Thus, the diagram portrays the observer effect not merely as an instructional mechanism but as a force that reconfigures the ontological fabric of student subjectivity.

The findings obtained from Table 3 align with Barad's (2007) view that the observer effect is not about passively recording reality but actively producing it. Students experience observation as a dual force: structuring their learning behaviors while simultaneously shaping their processes of identity formation**.** This dynamic parallels Foucault's (1982) theory of "subjectivation processes," where students are disciplined and positioned within performance-oriented identities under pedagogical surveillance.

While the observer effect elucidates how external gazes impose performative identities on students, the uncertainty principle metaphor further reveals the internal consequences of this imposition, exposing experiences of disorientation and indecision that destabilize the learner's sense of self.

According to Table 4, the metaphor of the Uncertainty Principle reveals that students confront not only knowledge but also indecision, fragility, and a loss of direction throughout their learning processes. The student appears not as a subject advancing along a fixed path, but as a pedagogical actor striving to exist on a constantly shifting, often destabilized ground of knowledge and identity.

The theme of "Indecision and Loss of Direction" focuses on instances where students become paralyzed and disoriented in the face of uncertainty. P2's statement, "I can't find my way; everything feels so uncertain," points not only to academic disorientation but to an existential loss of direction. Similarly, P5's comment, "There are always two paths in front of me, but I never know which one to choose," highlights how decision-making processes produce a sense of pressure and helplessness in the student.

The theme "Uncertainty in the Learning Process" reveals how students' trust in knowledge is continually shaken. P7's observation, "One day we learn something, and the next day new information arrives," expresses a loss of faith in the permanence of knowledge. Such epistemological shifts undermine not only the student's motivation to learn but also their trust in the educational system itself. P13's statement, "It feels like the knowledge we learn today becomes obsolete tomorrow," shows how this insecurity gradually internalizes into a deeper rupture.

Table 4. Thematic findings related to the uncertainty principle metaphor

Theme	Subtheme	Code	Frequency	Participant Description
Discontinuity of Identity	Fluctuation of Self-Positioning	I can't define myself – I'm one way one day, another the next	6	**P9:** 'I can't fix my identity – it's a slippery ground.'
	Sometimes I don't recognize myself	The question 'who am I' sometimes overwhelms me	5	**P6:** 'Sometimes I forget who I am.'
Indecision and Loss of Direction	Difficulty in Setting Goals	I lose my direction, I don't know which path to follow	8	**P2:** 'I can't find my way, everything feels uncertain.'
	I can't figure out what to do	I always have options but can't decide	5	**P5:** 'There are always two paths but I can't choose either.'
Uncertainty in the Learning Process	Everything changes too fast	I feel like knowledge is constantly being disproven	4	**P13:** 'What we learn today feels obsolete tomorrow.'
	Instability of Knowledge	Sometimes what I thought was right turns out wrong the next day	7	**P7:** 'One day we learn something, the next day it's replaced.'
	What I learn today feels outdated tomorrow	Most of what I learn changes so fast	6	**P10:** 'With technology, everything changes too quickly.'

The third theme, "The Discontinuity of Identity," discloses how uncertainty permeates not only the realm of knowledge but also the student's subjective existence. P9's remark, "I can't situate myself into a stable identity; it feels like slippery ground," suggests that within pedagogical contexts, the student is positioned not as a fixed subject but as a constantly shifting and redefined self. This conflict becomes even more radical in P6's expression, "Sometimes I feel like I forget who I am," making visible the fragmentation of the student's being.

Crucially, the frequency distribution of codes in Table 4 deepens our understanding of how pervasive these experiences of uncertainty are in educational contexts. Codes such as "difficulty in setting goals" (8) and "instability of knowledge" (7) show that uncertainty is not a marginal or exceptional experience but a systemic and recurring phenomenon for students. These high frequencies suggest that feelings of disorientation, epistemic fragility, and identity discontinuity are structurally embedded within the learning process, reinforcing the metaphor's relevance.

At the same time, lower-frequency codes like "fluctuation of self-positioning" (6) and "sometimes I forget who I am" (5) offer critical insights into the deeper existential dimensions of uncertainty. Although these narratives are less numerically dominant, they expose the subtle but profound ontological ruptures students experience. These codes reveal that uncertainty is not merely an external challenge related to knowledge acquisition but an internal struggle over maintaining a coherent sense of self amidst pedagogical expectations.

This thematic structure demonstrates that the metaphor of the Uncertainty Principle creates a profound field of tension not only at the level of knowledge but also within the very process of becoming a subject. Learning is no longer a linear process; rather, it unfolds on an ontological ground that is undecidable, unreliable, and impossible to stabilize. In this way, uncertainty has emerged as a central metaphor structuring the pedagogical experience of the contemporary student.

Figure 3 visually encapsulates this ontological destabilization by portraying the student as a fragmented, directionless entity navigating an ever-shifting landscape of knowledge and identity. The diagram emphasizes that learning does not progress through a clear trajectory but through non-linear, intersecting paths marked by indecision, discontinuity, and epistemic turbulence. This visual mapping not only illustrates the pedagogical implications of uncertainty but also critiques the educational system's failure to accommodate the inherent fluidity of the learner's becoming.

The existential dissolution brought about by uncertainty, and the pedagogical repositioning of the student's relationship with it, is visually represented in Figure 3.

Figure 3 conceptually represents the student, within the context of the uncertainty metaphor, not merely as experiencing cognitive confusion but as becoming pedagogically disoriented. This visual structure positions the student not as an autonomous subject with a stable identity but as a figure unable to make decisions, unable to stabilize knowledge, and unable to maintain a coherent sense of self. Rather than occupying a central locus, the student is situated within a fragmented epistemic field, where conflicting and discontinuous knowledge flows collide from multiple directions. This spatial arrangement emphasizes that learning is not a process of central progression but rather a dispersed, transient, and fragile mode of becoming.

Moreover, the non-linear structure of the figure demonstrates that the student's learning process does not fit within traditional pedagogical categories of progression or regression. Rather, the student is continuously repositioned among various fragments of knowledge. This condition transcends cognitive instability, revealing deep-seated ontological ruptures where the learner simultaneously pursues knowledge while questioning its permanence and reliability.

Thus, Figure 3 portrays learning not as a linear acquisition of information but as an ongoing negotiation of self amidst epistemic uncertainty. In this context, uncertainty emerges not as a pedagogical obstacle but as the foundational ontological condition of contemporary studenthood.

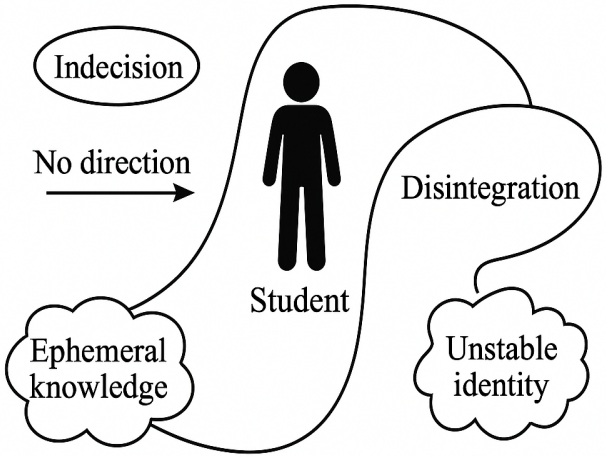

Figure 3. The student's directionless, transient, and fragmented pedagogical positioning within the metaphor of the uncertainty principle (Created using Microsoft PowerPoint)

The findings obtained from Table 4 are consistent with Heisenberg's (1958) epistemological and ontological interpretations of the uncertainty principle. Student identity and knowledge are neither fixed nor predictable; rather, they continuously shift depending on context, time, and observation. This also intersects with Biesta's (2004) emphasis on the illusion of "secure knowledge," highlighting that learning to live with uncertainty becomes an existential skill in education.

While the uncertainty principle elucidates the fragmentation students experience across identity and knowledge domains, the superposition metaphor extends this understanding by illustrating how students simultaneously inhabit multiple, overlapping identity positions within these fragmented realities.

According to Table 5, the superposition metaphor reveals that students do not possess stable and consistent identities but can simultaneously exist in multiple pedagogical, social, and emotional positions. This metaphor resonates not only in quantum physics but also in the fragmented and simultaneous identity experiences of contemporary students.

Under the theme of "Experiencing Multiple Identities," students expressed that they embody different identities depending on the context. P1's statement, "I am one person at school, another at home, and completely different with my friends," illustrates that these identity transitions are not random but are contextually triggered states of superposition. This experience makes it difficult for students to construct a coherent sense of self and weakens their sense of pedagogical belonging.

Table 5. Thematic structure related to the superposition metaphor

Theme	Subtheme	Code	Frequency	Participant Description
Conflict in Educational Orientation	Tension Between Personal and Environmental Goals	My family wants something, I dream of something else	5	**P13:** 'My family says engineering, but I dream of theater — there's so much pressure.'
	Uncertainty in Goals and Direction	I can't set goals because I'm not sure what I want	7	**P7:** 'I don't even have a career plan, because I can't decide on anything.'
Multiple Identity Experience	Mismatch Between Internal and External Identity	I act differently at school than I do at home	4	**P9:** 'Sometimes I feel like I forget who I really am when I'm at school.'
	Simultaneous Roles	While studying I'm a student, at home a brother, outside someone else	6	**P1:** 'I'm someone at school, someone else at home, and completely different with friends.'
Unresolved Learning States	Lack of a Stable Learning Style	Sometimes I'm highly motivated, other times completely indifferent	6	**P11:** 'One day my motivation is high, the next it hits rock bottom.'
	Unclear Learning Attitudes	Even I don't know how or when I actually learn	5	**P4:** 'I always find myself learning in different ways, but I can't settle into a routine.'

The theme of "Indeterminate Learning States" focuses on students' inability to maintain stability in their learning attitudes. P4's remark, "I always find myself learning in different ways, but I can't establish a consistent pattern," shows that not only learning styles but also the meanings attributed to learning are in constant flux. In such situations, the student struggles to define themselves as a learning subject, uncertain about what motivates them, what methods work, or what they believe in.

The theme of "Conflict in Educational Orientation" highlights the tension between students' internal desires and external expectations. P13's statement, "My family wants me to study engineering, but I am thinking about theater; there's a lot of pressure," shows that students can remain in a superposed state not only regarding career goals but also concerning the direction and purpose of their learning. This conflict impedes decision-making processes and produces a persistent sense of disorientation in the student.

In this context, the superposition metaphor associates the pedagogical subject not with stability but with multiplication, albeit at the cost of losing coherence within this multiplicity. Because the student cannot be anchored to a single role, identity, or learning attitude, they inevitably conflict with the educational system's expectation for clarity and consistency. This analysis indicates that in contemporary pedagogical environments, the student must be reimagined not as a singular, unified subject but as a dispersed and fragmented one.

The frequency analysis in Table 5 reinforces this interpretation by showing how recurrent these fragmented identity experiences are. Codes such as "uncertainty in goals and direction" (7) and "simultaneous roles" (6) indicate that students frequently navigate multiple, overlapping positions without being able to prioritize or integrate them. These frequencies demonstrate that the superposition metaphor is not a marginal phenomenon but a structural condition of the modern learning subject.

At the same time, lower-frequency codes like "mismatch between internal and external identity" (4) and "unclear learning attitudes" (5) reveal more subtle but equally critical dynamics. These codes highlight the internal conflicts students face when their self-perception diverges from external expectations or when their motivations fluctuate unpredictably. Though less numerically dominant, these experiences point to the psychological and emotional toll of inhabiting multiple, often contradictory identity positions.

Figure 4 visually synthesizes these complexities by depicting the student's pedagogical positioning as inherently multiple, scattered, and transient. The diagram illustrates how the educational system's demand for singularity and coherence clashes with the student's lived reality of superposed identities and shifting motivations. By mapping these tensions, Figure 4 offers a conceptual framework for understanding the superposition metaphor not just as a descriptive tool but as a critical lens for rethinking the ontology of the learner.

Within this framework, Figure 4 conceptually visualizes how the superposition metaphor generates multiple, scattered, and transient positionings in the student's process of pedagogical subjectivation.

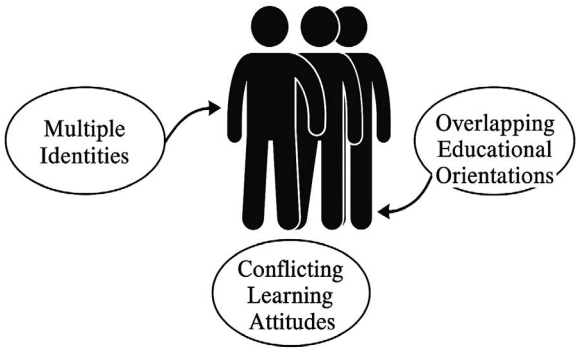

Figure 4. The student's multiple and indecisive pedagogical positioning within the metaphor of superposition (Created using Microsoft PowerPoint)

Figure 4 demonstrates that the student, within the pedagogical process, does not occupy a singular and coherent identity but rather exists simultaneously in multiple positions. The overlapping figures symbolize how the student carries different roles, conflicting learning attitudes, and orientations

at the same time. This multiplicity renders the student's pedagogical experience as a stratified process, shaped not only by knowledge acquisition but by continuous negotiations of identity, belonging, and directional orientation. The visual structure illustrates that the student does not maintain a fixed position but instead navigates between internal desires and external expectations, occupying unstable and transient positionalities.

In this framework, the superposition metaphor reframes the student as a relational and fragmented subject, perpetually reconfigured through contextual shifts, rather than as a stable educational entity.

The findings obtained from Table 5 offer a pedagogical analogy to the quantum principle of superposition: the student does not exist within a single, fixed identity but simultaneously inhabits multiple, often conflicting positions. This corresponds with Biesta's (2010) emphasis that "identity formation through learning" is not a closed process but one that remains in perpetual negotiation, and aligns with Barad's (2007) notion of ontological entanglement, where subjectivities emerge through relational intra-actions rather than pre-given structures.

Thus, the pedagogical subjectification of students materializes not as a linear trajectory but as an entangled experience of coexisting, transient, and sometimes contradictory positionalities.

The student's unfixable, multiple, and dynamic subjectivity is not only intertwined with the metaphor of superposition but also deeply resonates with the dynamics illustrated in wave-particle duality, observer effect, and uncertainty principle metaphors, collectively constituting a holistic quantum ontology of learning.

The complex structural relationships among these metaphors and the conceptual links between all codes are visually presented in Figure 5.

Figure 5. Hierarchical and thematic relationships of codes from four quantum metaphors (Created using Lucidchart)

Figure 5 reveals not only the thematic clustering of the codes derived from the four quantum metaphors but also the implicit transitions, points of intersection, and structural overlaps among these codes. The student is dynamically positioned along the axes of identity, knowledge, environmental pressure, and learning attitude, continuously shifting rather than occupying a fixed point. Therefore, rather than clear-cut separations between the metaphors, there are complementary, overlapping, and sometimes intersecting conceptual connections.

For instance, the links drawn between the codes of "inability to define oneself," "role-playing," and "experiencing multiple selves" show how the student's identity is reconstructed both through external observation and internal disorientation. Similarly, the connections among 'the transience of knowledge,' 'indecisiveness,' and 'instability of learning styles,' although categorized under different metaphors, collectively produce a narrative of how the student becomes disoriented within an epistemological void.

The web-like design of the map illustrates that these codes are not confined to their respective metaphors but instead shape the pedagogical subject multidimensionally through cross-transitions. Reinforcing this structure, the student's learning existence unfolds as multi-centered and circular, mirroring the fragmented nature of contemporary studenthood, the continuous movement of pedagogical identity, and the pervasive insecurity regarding knowledge.

Figure 5 embodies not a static conceptual map, but a dynamic field where the pedagogical subject's quantum-like oscillations materialize, offering a visual ontology of learning that challenges linear and compartmentalized educational models.

Discussion

The findings of this study indicate that quantum metaphors function as more than analogical tools in educational contexts; they offer interpretative spaces through which students articulate and negotiate their learning identities. The metaphors of wave-particle duality, observer effect, uncertainty principle, and superposition enabled participants to express experiences that might otherwise remain implicit, particularly regarding the fluid and context-dependent nature of their educational subjectivities (Doll, 1993; Lakoff & Johnson, 2003).

In the case of wave-particle duality, students often described shifts in their learning identity depending on classroom context, interaction with peers or teachers, and assessment practices. These descriptions illustrate that learner identity is not fixed but constantly reconstructed through changing pedagogical conditions (Mitchell et al., 2016; Whitehead, 1978). For example, some participants described moments when they felt confident and expressive in oral contexts yet constrained and hesitant in written examinations, showing how educational environments privilege certain performances over others.

The observer effect metaphor revealed how the perceived presence of authority figures influenced students' engagement and self-perception. Several participants noted that their behavior, confidence, and even self-definition changed when they felt under observation. This resonates with Barad's (2007) view that observation is not a neutral act but one that actively shapes the phenomenon being observed. In educational contexts, such observation often translated into self-monitoring and a heightened sense of vulnerability.

The uncertainty principle metaphor was used by participants to convey the instability and unpredictability of

their learning trajectories. Students associated uncertainty with both difficulty in setting fixed goals and the challenge of maintaining a coherent sense of self within an evolving educational journey. While some framed this instability as a source of anxiety, others perceived it as an opening for flexibility and adaptation, aligning with perspectives that see uncertainty as a generative condition for learning (Peters, 2019; Taylor, 2013).

Finally, the superposition metaphor captured the coexistence of multiple roles, attitudes, and self-understandings within the same learner. Participants often spoke of simultaneously occupying different and even conflicting positions, such as being both confident in subject mastery yet doubtful about future academic paths. This multiplicity highlights that students navigate learning not as a linear progression but as a continual balancing of competing demands and aspirations.

Rather than introducing a new theoretical framework disconnected from the data, these findings point toward the relevance of existing perspectives in poststructuralist and posthumanist educational theory (Snaza & Weaver, 2015; Taylor & Hughes, 2016). The metaphors used by students invite a pedagogical approach that recognizes learning as a process of negotiating identity, meaning, and relational positioning within dynamic and sometimes contradictory contexts. Such an approach shifts attention from fixed outcomes toward the lived, interpretative experiences of learners, consistent with the principles of Interpretative Phenomenological Analysis (Smith et al., 2009), which prioritize depth of meaning over frequency counts.

Conclusion

Returning to the central inquiry of this study, quantum metaphors have demonstrated their conceptual power in redefining how the pedagogical being of the student is understood. Rather than merely serving as analogical tools, these metaphors illuminate the fluid, relational, and context-dependent nature of student subjectivities. The findings reveal that students do not possess fixed identities or learning trajectories; instead, they navigate educational environments through continuously shifting, contextually mediated experiences of self.

The wave-particle duality foregrounds this dynamic by showing how learners oscillate between modes of being, resisting simplistic categorizations of success and failure. Similarly, the observer effect underscores the material-discursive role of educational practices in shaping, not merely recording, student realities. The uncertainty principle problematises linear and deterministic models of learning, while the superposition metaphor captures the multiplicity of roles and desires that coexist within the learner.

In practical terms, these insights suggest that educational practices should move beyond standardized, outcome-driven models toward more relational and flexible approaches. For instance, integrating quantum metaphors into teacher reflection practices could help educators recognize and respond to the evolving, situational identities of their students. Assessment methods might also be reimagined to accommodate the non-linear, emergent nature of learning, valuing processual engagement over fixed competencies.

The ontological lens provided by quantum metaphors thus compels a rethinking of foundational educational assumptions. Rather than viewing learning as the mere accumulation of knowledge or skills, this perspective emphasizes the co-constitutive interplay between learner, context, and pedagogical interaction. In doing so, it reframes the student not as a static, measurable subject but as a situated, dynamically becoming presence within the educational process.

Ultimately, the study proposes that embracing ontological multiplicity and uncertainty is not a limitation but an ethical imperative for contemporary education. By honoring the complex and fluid nature of student subjectivities, educators can foster learning environments that are more inclusive, responsive, and attuned to the realities of pedagogical existence.

Recommendations

Assessment processes within educational systems should not be limited to determining "what the student is" at a given moment; rather, they should aim to create pedagogical environments that support the student's processes of becoming and transformation. Educational institutions must develop flexible, relational, and process-centered evaluation models that provide space for the learner's potential multiplicity and contextual existence.

Moreover, strengthening metaphor-based ontological sensitivity within teacher education programs has become a critical necessity. Future teachers must be philosophically equipped to conceptualize the learner not as a fixed subject, but as a being that changes with context, remains open to observation, and carries multiple identities. Integrating quantum metaphors into teacher education can cultivate a powerful awareness in this regard (Peters, 2020). Thus, a quantum-based pedagogical approach would not only respond to the complex educational needs of contemporary society but could also restructure educational systems with transformative potential.

Author Contributions

The author declares that no other author has contributed to this study and confirms that they have read and approved the final version of the manuscript.

Ethical Declaration

This study was conducted with the approval of the Bayburt University Ethics Committee, granted by the decision numbered 199 during the fifth session meeting held on 07.05.2025.

Conflict of Interest

The author declares that there is no conflict of interest with any institution or individual within the scope of this study.

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Appendix: Conceptual clarification of quantum metaphors

This appendix provides conceptual clarifications of the quantum metaphors referenced in the study, aiming to support readers in understanding the relationship between their physical meanings and pedagogical interpretations (Barad, 2007; Bohr, 1958; Fenwick & Edwards, 2012; Heisenberg, 1958; Saban, 2006; Sfard, 1998).

1. Wave-particle duality

In quantum physics, wave-particle duality refers to the phenomenon where entities such as electrons and photons exhibit both wave-like and particle-like properties depending on how they are measured. This challenges the classical notion of fixed, intrinsic states, emphasizing that the nature of a quantum entity is determined through observation (Bohr, 1958; Heisenberg, 1958). In the pedagogical context, this metaphor illustrates the fluid, context-dependent, and multiple nature of learner identity, which resists fixed categorizations (Barad, 2007; Sfard, 1998).

2. Observer effect

The observer effect describes how the act of observing or measuring a quantum system inevitably alters its state. In quantum mechanics, observation is not a passive process but an active intervention that shapes reality (Bohr, 1958; Heisenberg, 1958). Pedagogically, this metaphor signifies how students' behaviors, self-perceptions, and identity constructions are influenced and transformed through external attention, evaluation, and surveillance (Barad, 2007, 2012; Foucault, 1982).

3. Uncertainty principle

Heisenberg's uncertainty principle posits that certain pairs of properties (such as position and momentum) cannot be precisely known simultaneously. This principle reveals the inherent limitations of objective knowledge and the fundamental indeterminacy of reality (Heisenberg, 1958). As a metaphor, it represents the instability, fragmentation, and constant negotiation of knowledge and identity that students experience in learning processes (Biesta, 2004; St. Pierre, 2013).

4. Superposition

Superposition refers to the ability of a quantum system to exist in multiple states simultaneously until an observation collapses these states into a singular outcome (Bohr, 1958; Heisenberg, 1958). In educational contexts, this metaphor captures how students simultaneously embody multiple, and sometimes conflicting, roles, identities, and learning orientations, which are often reduced to singular, standardized identities under institutional pressures (Barad, 2007; Biesta, 2010).