Journal of Research in Science, Mathematics and Technology Education

https://jrsmte.com/

Measured Without Meaning: Data Subject Consciousness in Technology-Mediated STEM Learning Environments: A Phenomenological Case Study

Joshua M. Jonas

Baylor University, United States of America

Abstract: Across STEM education, healthcare, and workplace settings, individuals increasingly learn and perform within data-rich environments where measurement systems generate information about their bodies and behaviors that they cannot access or interpret. This study introduces data subject consciousness, the epistemological condition of knowing oneself as a data source while being structurally excluded from interpreting that data, through phenomenological analysis of a paradigmatic case: an elite athlete navigating sports science technology. Through a 60-minute narrative interview with a Brazilian Olympic sprinter (400m) now pursuing doctoral training in Exercise Physiology, and following Moustakas's (1994) phenomenological methodology, five themes illuminate how learners experience the gap between being measured and making meaning: data opacity, the displacement of embodied knowing by objective measurement, the knowledge mediator, the paradox of wearable technology, and resource constraints limiting interpretive access. The study argues that sport provides an analytically clear case for understanding a broader epistemic condition increasingly visible in STEM learning environments, including science classrooms, learning analytics systems, and AI-mediated instruction, where learners and teachers face structurally similar exclusions. Data subject consciousness offers a diagnostic framework for researchers and designers of educational technology who seek to build systems that support rather than foreclose interpretive participation by learners.

Keywords: *data literacy; data subject consciousness; epistemic access; epistemic injustice; learning analytics; STEM education; technology-mediated learning*
DOI: https://doi.org/10.31756/jrsmte.514SI

Introduction

In STEM education, datafication is no longer a future condition, it is the present architecture of learning. Students in science classrooms generate performance data through adaptive platforms that track response patterns, engagement metrics, and learning trajectories (EDUCAUSE, 2024). Teachers receive algorithmic outputs about student progress from systems whose internal logic remains inaccessible (Zhou et al., 2024). Learning analytics tools monitor behavioral patterns and surface recommendations that shape instructional decisions, yet research suggests that such dashboards, while increasingly common, have not consistently supported meaningful learning outcomes or interpretive participation by learners (Kaliisa et al., 2023). Wearable biosensors appear in physical education, kinesiology programs, and health science curricula, extending physiological monitoring into formal learning contexts (EDUCAUSE, 2022). In each of these contexts, learners and teachers are frequently positioned as data sources, their performance, attention, and physiology continuously measured, yet they often lack access to the interpretive frameworks that would allow them to make sense of what that data means. This paper argues that this structural condition constitutes a distinct epistemological problem with significant consequences for learning, professional development, and the design of educational technology systems.

To develop this argument, this study draws on a paradigmatic case from a domain where datafication has been particularly intense and its effects on subject experience particularly visible: elite sport. The phenomenological account of a Brazilian Olympic sprinter, who experienced systematic data collection throughout her athletic career

without interpretive access, and who now holds the scientific knowledge to understand retrospectively what was collected, provides an analytically exceptional window into what this paper calls data subject consciousness. Defined precisely, data subject consciousness is the epistemological condition constituted by three simultaneous features: (a) conscious awareness of being measured, monitored, and quantified; (b) recognition that this measurement produces meaningful data that shapes decisions about one's performance or body; and (c) structural exclusion from the interpretive frameworks that would render those measurements intelligible. This consciousness is not about surveillance anxiety or data privacy in the general sense. It names the specific lived experience of knowing oneself as a data source without achieving epistemic participation in data interpretation, a distinction that recent pedagogical research has begun to address by designing explicitly for learner interpretive capacity and what scholars have termed data agency (Pope et al., 2024; Vartiainen et al., 2025).

Sport provides an unusually clear empirical case for this concept because the data collection is embodied, immediate, and consequential in ways that make exclusion from interpretation viscerally apparent. But the structural condition data subject consciousness describes is not unique to sport. It increasingly characterizes the position of students navigating learning analytics systems they cannot interrogate, of teachers implementing AI-generated instructional recommendations they cannot evaluate, and of STEM learners whose performance data shapes educational trajectories they do not fully understand. Student-centered research in multimodal learning analytics has found that learners themselves express concerns about fairness, transparency, accountability, and the need for ongoing rather than one-off consent in how their data is used (Jin et al., 2024a). This paper uses the athlete's phenomenological account to develop a concept and framework applicable across these educational contexts. The goal is to make it impossible for STEM education researchers and educational technology designers to encounter measurement-intensive learning environments without asking: are the subjects of this measurement also participants in its interpretation?

The proliferation of data collection technologies in athletic training contexts increasingly parallels what is occurring in STEM education. Contemporary athletes train amid GPS trackers, heart rate variability monitors, DEXA scanners, and metabolic testing equipment (Jones & Sheffield, 2019; Mears et al., 2019), instruments that promise evidence-based precision over intuition (Postma & Dees, 2024; Robertson et al., 2017). STEM learners increasingly encounter analogous infrastructures: adaptive learning platforms, biometric attendance systems, cognitive load sensors, and performance dashboards that generate AI-supported models of engagement and performance (Zhou et al., 2024; EDUCAUSE, 2024). In both domains, the promise is optimization through data. In both domains, the question of who interprets that data, and who is excluded from interpretation, has received insufficient attention in the design of these systems (Kaliisa et al., 2023).

Research Questions

This study is guided by one central research question and two analytic subquestions. The central research question asks: How is data subject consciousness experienced by a learner who is continuously measured yet excluded from

interpreting the data generated about her body and performance? The first subquestion asks: What experiential structures or themes constitute data subject consciousness in this case? The second subquestion asks: What does this phenomenological case suggest for STEM learning environments in which learners and teachers are measured through learning analytics, AI systems, dashboards, or sensing technologies? The first subquestion shapes the Findings section; the second shapes the Discussion and Implications.

Literature Review

Data-Rich Learning Environments and the Problem of Interpretive Access

The expansion of learning analytics, AI-driven adaptive systems, and data-informed instruction has generated substantial scholarship on how institutions collect and use learner data. Researchers have examined the predictive validity of analytics tools (Siemens, 2013), the ethical dimensions of learner surveillance (Prinsloo & Slade, 2017), and the organizational challenges of translating data into instructional action (Mandinach & Gummer, 2016). More recent systematic review has tempered early optimism, finding that learning analytics dashboards are now widespread but have not consistently improved achievement, and that the field continues to struggle with transparency and interpretability for end users (Kaliisa et al., 2023; Zhou et al., 2024). This literature has productively scrutinized how institutions use data about learners. It has paid considerably less attention to how learners experience being datafied, what it feels like to generate data that shapes decisions about one's educational trajectory while being excluded from interpreting it. This experiential gap is precisely what data subject consciousness names.

Research on data literacy in STEM education has emphasized developing students' capacity to read, analyze, and interpret data (Gould, 2017; Makar & Rubin, 2009), and a more recent strand has begun to foreground socio-technical and ethical dimensions, teaching learners to understand how data systems such as tracking, profiling, and recommendation engines actually operate (Pope et al., 2024; Tadimalla & Maher, 2024). Yet this literature implicitly positions students as analysts of external datasets, or as developing critical readers of data systems in general, rather than as subjects of the specific data systems that measure them. Students learning to interpret scientific data in chemistry or biology classrooms are in a fundamentally different epistemic position from students whose own performance data is being interpreted by adaptive platforms on their behalf. The latter condition, being a data subject in one's own learning environment, has received insufficient theoretical and empirical attention, though emerging intervention research suggests that learners' data agency can be deliberately cultivated through classroom design (Vartiainen et al., 2025). Sports science provides a paradigmatic case of what this condition looks like when it is extreme and sustained.

Technology-Mediated Knowledge and Expert Mediation

A central concern of science education research is how expert knowledge becomes accessible to learners, how conceptual frameworks, disciplinary vocabularies, and interpretive tools are transmitted, scaffolded, or withheld

(Vygotsky, 1978). In STEM contexts, this question typically concerns how teachers mediate between disciplinary knowledge and learner understanding. Data subject consciousness surfaces a related but distinct problem: how knowledge mediators, whether coaches, teachers, or algorithms, can become monopolistic gatekeepers who control not just the transmission of knowledge but the interpretive access learners have to data generated by their own performance.

In sports science contexts, Akenhead and Nassis (2016) documented that while data collection is widespread in elite athletic programs, coaches frequently lack the statistical literacy to interpret and apply measurement findings, creating persistent disconnects between collection and utilization. This mirrors findings in educational technology research: data dashboards and analytics tools are widely adopted but rarely used in ways that meaningfully support learning decisions (Mandinach & Gummer, 2016). Studies of teachers working with classroom analytics show that they do not simply receive data outputs but must actively contextualize and interpret them, often experiencing dissonance before they learn to make analytic traces meaningful for instruction (Ngoon et al., 2024; Johnston & Jendoubi, 2024). The parallel is structural: in both domains, data collection infrastructure has outpaced interpretive infrastructure, and the subjects whose performance is measured are the ones most consistently left outside the interpretive process.

Phenomenological Research in Technology-Mediated Learning

Phenomenological approaches have been productively applied in STEM education and educational technology research to illuminate how learners experience technology-mediated environments (Ihde, 1990; Verbeek, 2005), how students make sense of scientific measurement practices (Roth & Roychoudhury, 1993), and how embodied knowledge relates to formal scientific representation (Merleau-Ponty, 1962; Varela et al., 1991). These traditions provide the conceptual vocabulary this study draws on to analyze athlete experience. Phenomenological approaches in sport research have similarly examined how practitioners experience measurement and monitoring technologies (Allen-Collinson, 2009; Hockey & Allen-Collinson, 2007), though investigation of the specific experience of data subject consciousness, the consciousness of being excluded from interpreting one's own data, remains minimal. Student-centered work in multimodal learning analytics has begun to approach this experiential dimension, documenting that learners actively evaluate the fairness, transparency, and accountability of the systems measuring them and express clear preferences about access to and consent over their own data (Jin et al., 2024a).

Theoretical Framework

Three theoretical perspectives converge to frame data subject consciousness as an educationally relevant construct. Phenomenological philosophy, developed through Husserl, Heidegger, and Merleau-Ponty, attends to structures of conscious experience, how subjects make meaning within their lived worlds (Moustakas, 1994; van Manen, 2016). This study employs phenomenology to illuminate how a learner-subject experiences data-generating technologies as meaningful or opaque, and how that experience shapes knowledge, self-relation, and epistemic positioning within an institution.

Postphenomenology, developed by Ihde (1990) and Verbeek (2005), extends this analysis to human-technology relations. Technologies actively mediate experience: embodiment relations (technology becomes transparent, as with eyeglasses), hermeneutic relations (technology requires interpretation, as with thermometers), and alterity relations (technology becomes quasi-other). Sports science monitoring technologies, and their educational equivalents in adaptive learning platforms and student dashboards, aspire to embodiment transparency but demand hermeneutic interpretation that learners lack resources to perform. This postphenomenological lens explains why data systems designed for transparency so frequently produce opacity for their subjects.

Fricker's (2007) framework of epistemic injustice provides vocabulary for naming the educational stakes of this condition. Hermeneutical injustice occurs when individuals lack the conceptual resources to make sense of their own experiences, not because of individual limitation but because interpretive frameworks have been institutionally withheld. Athletes subjected to sports science measurement, and students subjected to learning analytics, arguably suffer this condition: they possess legitimate experiential knowledge yet lack access to the interpretive architecture that would render institutional data about them intelligible. Foucault's (1975) analysis of panoptic surveillance further illuminates how measurement technologies produce self-regulatory effects through the mere consciousness of being monitored, a dynamic equally visible in athletic training environments and in STEM classrooms equipped with behavioral tracking infrastructure.

Methodology

This study employs Moustakas's (1994) phenomenological research methodology to investigate the lived experience of data subject consciousness through a paradigmatic case. Phenomenological methodology is particularly appropriate here because the research question concerns the structure of a specific form of consciousness, the experience of being a data subject without interpretive access, rather than the frequency or distribution of that experience across a population.

Ethical Considerations and IRB Determination

This study received a formal determination of non-human subjects research from the Institutional Review Board at Baylor University (IRB Reference #2408191, March 4, 2026), pursuant to federal regulations at 45 CFR 46.102(e) and (l). The IRB determined that this activity does not meet the regulatory definition of human subjects research because the findings are not designed to be generalized to a broader population, a determination consistent with phenomenological methodology's aim to illuminate essential structures of experience rather than produce statistically generalizable claims. Informed consent was obtained from the participant prior to data collection. The participant is identified by pseudonym throughout, and all identifying details have been managed to protect confidentiality.

Methodological Justification for Single-Participant Design

Phenomenological inquiry does not seek statistical representativeness; it seeks structural insight into essential features of lived experience (van Manen, 2016). Validity is indexed to depth, richness, and structural clarity rather than sample size (Moustakas, 1994). Single-participant phenomenological designs have established precedent in educational research precisely because they enable the depth of experiential analysis that reveals structural conditions invisible to larger, thinner studies. Marina's unique positioning, as both former elite athlete who experienced data subject consciousness and current doctoral researcher in Exercise Physiology who now possesses the interpretive frameworks she previously lacked, provides an analytically exceptional case. She can articulate both the immediate lived experience and its retrospective recognition, offering phenomenological depth uniquely suited to illuminating the structure of this consciousness. The broader educational implications developed in this paper are theoretical extensions grounded in the structural logic of the concept, not empirical generalizations from a single case. The purpose is not generalization but analytic illumination of a structural condition increasingly present in STEM learning environments.

Participant and Context

I recruited Marina (pseudonym), a former Brazilian Olympic sprinter (400m) now pursuing doctoral training in Exercise Physiology, through purposive sampling. Marina's career included extensive exposure to sports science monitoring: psychological testing, computerized strength evaluation, sleep monitoring, DEXA body composition scanning, and lactate threshold testing across training contexts in Brazil, the Caribbean, and the United States. As she consistently emphasized, she received virtually no interpretive feedback during her athletic career, data was collected systematically and rarely communicated back in accessible form. Marina now possesses the scientific training to understand retrospectively what was measured throughout her career, making her account exceptionally valuable for illuminating the structure of data subject consciousness from both inside and outside the condition.

Data Collection and Analysis

I conducted a single 60-minute narrative interview with Marina via video conference in November 2025. Following Clandinin and Connelly's (2000) narrative inquiry principles, I opened with broad, experience-centered prompts designed to elicit storytelling rather than impose predetermined categories, inviting Marina to describe her experiences with sports science technology throughout her athletic career and to reflect on how her scientific training has transformed her understanding of those experiences.

Analysis followed Moustakas's (1994) phenomenological reduction procedures: epoche (bracketing my own assumptions as an educational technology researcher); horizonalization (treating each experientially significant statement as having equal value); iterative clustering of meaning units into themes capturing essential dimensions of Marina's experience; textural descriptions (what she experienced) and structural descriptions (how she experienced

it); and synthesis into an essence statement articulating the fundamental structure of data subject consciousness as she lived it.

Researcher Positionality

My positioning as an educational technology researcher, rather than a sports scientist, shaped this analysis productively. As an outsider to elite athletic culture, I was genuinely surprised by the systematic interpretive exclusion Marina described, which prevented normalization of a condition that deserves critical scrutiny. My educational technology background attuned me to parallels between Marina's experience and learner experience in technology-mediated educational environments, the theoretical extension this paper develops. I bracketed assumptions about data transparency derived from educational contexts throughout analysis, and used reflexive memos to track where my positioning influenced interpretation.

Findings

The following five themes address the study's central research question, how data subject consciousness is experienced by a learner who is continuously measured yet excluded from interpreting the data generated about her body and performance, and its first subquestion concerning the experiential structures that constitute this condition. These themes emerged inductively from Marina's own account through systematic phenomenological reduction rather than being imposed by theoretical preconceptions. They collectively reveal how a learner embedded in a data-rich technological environment experiences the gap between being measured and making meaning, a structure with direct analogs in STEM education and technology-mediated learning contexts.

Theme 1: Data Opacity, Technology as Black Box

Marina repeatedly described sports science testing as simultaneously sophisticated and incomprehensible, producing outputs that clearly mattered to decision-makers while remaining fundamentally opaque to her as the subject of measurement. Recalling her first encounter with computerized strength testing at the Brazilian Olympic Training Center:

> I don't know what it means. Nobody ever explained that to me, but that looks cool. So I think that was my first perspective... And even when, before going to the Olympics, we had one day of testing where we would go to all of those different professionals, we slept in a specific room and we had all of this technology into helmets and so on. And I never received information.

The systematic nature of this exclusion extended across all measurement modalities: "With the DEXA scan, I know my body fat percentage, but I don't know what that means... With the sleep, I never received information. With the blood draws, I never received information. With the VO2 max, I also didn't receive information." Technology functioned as what Ihde (1990) terms hermeneutic black boxes, systems that transform inputs into outputs through processes inaccessible to those who generate the inputs. The opacity was structural rather than individual: Marina's

doctoral training has since revealed that comprehension was always possible, that the frameworks needed to interpret her own data were learnable. What prevented understanding was not the inherent difficulty of sports science concepts but the systematic withholding of interpretive access. This structural opacity is directly parallel to what students encounter in adaptive learning systems whose recommendation logic is opaque, and in learning dashboards that display metrics without explanation.

Theme 2: Embodied Knowing vs. Objective Measurement

Marina developed sophisticated kinesthetic knowledge through years of high-level training, awareness of recovery states, fatigue patterns, and performance readiness grounded in proprioceptive feedback and accumulated experience. This embodied knowing constituted legitimate expertise. Yet sports science measurement practices systematically positioned it as subjective and therefore unreliable, requiring correction through objective data: "As a scientist I understand how important that is, but as an athlete, that was not how things were communicated."

This hierarchical positioning, in which quantitative measurement claims epistemic authority over embodied practical knowledge, constitutes what Fricker (2007) terms testimonial injustice: the systematic discounting of a knower's credibility because their knowledge takes a non-sanctioned form. In STEM education, parallel dynamics operate when students' intuitive understanding of phenomena, developed through embodied experience, is dismissed in favor of formal measurement without pedagogical integration of both. The displacement of embodied knowing by abstract representation reflects what Dreyfus (2002) identifies as a characteristic tendency of technical rationality, and one that educational technology systems routinely reproduce when they position learner experience as noise to be corrected by algorithmic output. Marina's account also revealed a doubling of consciousness: she began experiencing her own performance simultaneously as lived (felt, sensed, inhabited) and as represented (measured, quantified, evaluated by others), a split awareness with direct implications for how learners in monitored educational environments experience their own cognition and performance.

Theme 3: The Knowledge Mediator as Epistemic Gatekeeper

Throughout Marina's athletic career, coaches functioned as sole knowledge mediators, receiving data, interpreting it, and translating it into directives without athlete participation in the interpretive process. Marina described this dependency through a religious metaphor that captures its totality:

> Whatever the coach says, it's usually the Bible. Especially whenever you're training for someone and you have a coach, you trust them and you believe that they know more than you do and that they're gonna be able to guide you towards becoming the best athlete that you can be.

This hermeneutic monopoly, controlling both technical interpretation and institutional authority over how data shapes decisions, positioned Marina as an epistemically dependent learner despite being the source of the data itself. In STEM educational contexts, teachers occupy a structurally analogous position when they serve as sole mediators

between algorithmic outputs and student understanding. But AI systems in education increasingly displace even teacher mediation, positioning the algorithm itself as knowledge gatekeeper. When learning management systems generate recommendations, flag at-risk students, or determine content pathways based on models learners cannot interrogate, the hermeneutic monopoly is no longer held by a human professional whose reasoning can be questioned, it is encoded in an opaque system. Foucault's (1975) analytics of pastoral power illuminate this dynamic: data mediators exercise care through knowledge systems that position subjects as objects requiring expert guidance rather than as participants capable of self-understanding.

Theme 4: The Wearable Paradox, Measurement Without Empowerment

Marina identified a paradox at the heart of wearable monitoring technology, devices designed to empower through self-knowledge that instead become instruments of confrontation with quantified inadequacy:

> I think wearables can be really helpful, but I also think they can be problematic... maybe I already know that I'm not gonna sleep well tomorrow, but I'm still tracking my sleep because I need to have it. So I think that can be problematic because then you're already tired, but then you keep seeing that you're tired.

This observation reveals what might be called the wearable paradox: technologies designed to empower subjects through data instead intensify data subject consciousness when they provide continuous metric confrontation without interpretive resources or actionable guidance. The parallel in educational technology is direct. Student-facing dashboards that display performance metrics without scaffolded interpretation, adaptive systems that communicate learner inadequacy through deficit-framed outputs, and monitoring tools that track engagement through behavioral proxies without explaining what those proxies measure, all reproduce the wearable paradox in learning environments. Moreover, the presence of monitoring infrastructure transforms the phenomenology of learning itself: students who know their engagement, responses, and behavioral patterns generate evaluable data modify their performance in anticipation of algorithmic assessment, regardless of whether anyone actively reviews their data, the panoptic effect Foucault (1975) describes.

Theme 5: Resource Constraints and Differential Epistemic Access

Marina's experience in resource-constrained training contexts, Brazil and the Caribbean, added a material dimension to her epistemic exclusion. She contrasted these contexts with better-resourced environments: "I'm from Brazil... we don't have as much investment in sports. At least track, maybe with soccer is different." In under-resourced settings, equipment was borrowed for single sessions, sports scientists participated sporadically, and coaches lacked interpretation training, meaning data was sometimes collected without being meaningfully interpreted by anyone.

In STEM education, this differential manifests as the data literacy gap: students in under-resourced schools receive AI-driven instructional tools not designed for their contexts, without teachers who have received adequate professional development to interpret or mediate those tools' outputs, within systems that generate data about

student performance without local capacity to use it meaningfully (Baek et al., 2023). The same structural condition Marina experienced across two different resource environments is reproduced across different school contexts, a finding with significant implications for educational equity and technology design.

Discussion

Data Subject Consciousness as an Educational Construct

This section addresses the study's second subquestion, what this phenomenological case suggests for STEM learning environments in which learners and teachers are measured through learning analytics, AI systems, dashboards, or sensing technologies. Synthesizing across the five themes that emerged from Marina's phenomenological account, data subject consciousness is constituted by three simultaneous elements: awareness of being measured, recognition that measurement produces consequential outputs, and exclusion from the interpretive frameworks that would make those outputs legible. This structure was not theorized in advance but surfaced inductively through careful phenomenological analysis of Marina's lived experience. Learners experiencing this consciousness exist in a doubled epistemic state, generating data about their own performance while being unable to participate in determining what that data means. Recent student-centered research in learning analytics confirms that learners actively recognize and respond to this condition: students in multimodal learning analytics contexts have expressed concerns about fairness, transparency, differential data access, and the need for ongoing consent, concerns that reflect the same epistemic exclusion Marina experienced (Jin et al., 2024a). This doubling creates what the findings reveal as epistemological estrangement: one's own performance or body becomes partially alien, knowable fully only through expert mediation that remains perpetually out of reach.

Two mechanisms sustain this condition. Estrangement operates internally, transforming how subjects relate to their own knowing, splitting lived performance experience from its quantified representation without providing bridges between these modes. Research on learning analytics has documented that black-box systems actively prevent users from obtaining educationally meaningful interpretations, reinforcing estrangement rather than resolving it (Zhou et al., 2024). Surveillance operates externally, producing self-regulatory behavior through the internalized awareness of being continuously monitored. Both converge in data subject consciousness, positioning learners simultaneously as data sources and as epistemically excluded subjects who regulate their performance for an imagined algorithmic audience. Emerging scholarship on responsible AI in education identifies these dynamics, opacity, limited stakeholder involvement, and insufficient attention to user trust, as unresolved challenges across the field (Hooshyar et al., 2025).

Marina's transformation from athlete to sports scientist illuminates the condition's reversibility. Her retrospective account, "I think it's unfortunate... as a scientist I understand how important that data is, but I also understand how important it is to communicate that back to the athlete", demonstrates that data subject consciousness is not a natural consequence of datafication. It is a structural effect of how knowledge systems organize interpretive access. When learners gain conceptual frameworks adequate to their data environments, opacity dissolves. Recent pedagogical

research supports this inference: structured classroom interventions designed to develop children's understanding of data mechanisms, including how tracking, profiling, and recommendation systems work, have produced significant improvements in learners' data agency and their capacity to explain those mechanisms (Vartiainen et al., 2025; Pope et al., 2024). This finding has a direct educational implication: interpretive access is teachable, and the responsibility for teaching it belongs to educational institutions and technology designers, not to learners who must acquire it independently.

Implications for STEM Education Research and Practice

Data subject consciousness reframes a central question for STEM education: not only how we teach students to analyze data, but how we design the data environments students inhabit so that those environments support rather than foreclose learner epistemic participation. Recent reviews and institutional reports suggest that many analytics infrastructures remain oriented primarily toward institutional decision-making, with learner-facing interpretive support still underdeveloped (Kaliisa et al., 2023; EDUCAUSE, 2022). Student-centered research further indicates that learners want more transparency, accountability, and differentiated access to their own data than systems commonly provide (Jin et al., 2024a). Data subject consciousness provides a diagnostic framework for evaluating these systems against a different criterion: does this system position learners as data sources or as epistemic participants?

For educational technology designers, the concept suggests four design imperatives grounded in current scholarship. First, transparency at the point of consequence: learners should understand what systems are measuring, how measurements are interpreted, and how outputs influence decisions about their learning, not as a privacy disclosure but as an epistemic right (EDUCAUSE, 2025; Jin et al., 2024a). In a high school science classroom, this would mean that when an adaptive platform adjusts a student's learning pathway, the student receives a legible explanation of why, not a redirect to a different content module without rationale. Second, interpretive scaffolding: data systems should provide learners with the conceptual tools to evaluate algorithmic outputs rather than simply receive them. Research on transparent learning analytics and AI-assisted dashboards suggests that explanatory interfaces can improve learner comprehension, though their effectiveness depends on whether literacy supports are built into the interaction design (Zhou et al., 2024; Jin et al., 2024b). A concrete STEM scenario: a chemistry student whose automated lab performance report flags low scores should receive not just a score but a guided explanation of what the score measures, what it does not measure, and what interpretive steps are available. Third, embodied knowledge integration: systems should treat learner experience and self-assessment as complementary epistemic resources rather than as subjective noise requiring algorithmic correction. Studies of teacher interpretation of classroom data show that analytic traces require contextualized human judgment rather than decontextualized metric consumption, and that teachers must be supported to provide that judgment (Ngoon et al., 2024; Johnston & Jendoubi, 2024). Fourth, mediator accountability: where human professionals, teachers, coaches, advisors, function as knowledge mediators between data systems and learners, institutions should ensure those professionals have both the

interpretive capacity and the professional obligation to share interpretation with learners, not merely to act on it (EDUCAUSE, 2025; Hooshyar et al., 2025).

For STEM education researchers, data subject consciousness opens a productive empirical agenda. How do students experience adaptive learning platforms that modify their educational pathways based on opaque algorithmic processes? What is the phenomenology of receiving AI-generated feedback on STEM performance? How do resource inequalities compound epistemic exclusion in data-intensive STEM learning environments (Baek et al., 2023)? Do students who understand the interpretive frameworks underlying their performance data learn differently, or relate to scientific measurement differently, than students who do not? These questions follow directly from the concept this study develops and suggest a research program that attends to learner experience as centrally as it attends to institutional outcomes. Emerging curriculum frameworks in AI literacy and data literacy, particularly those oriented toward socio-technical rather than purely technical understandings, offer one productive starting point for such a program (Tadimalla & Maher, 2024).

Limitations and Future Directions

This study examined one participant's retrospective account, providing depth at the expense of breadth. The theoretical extension to STEM education contexts is conceptual rather than empirically grounded in educational data, a limitation that the future research agenda above is designed to address. The findings illuminate the structure of data subject consciousness with clarity, but empirical investigation is needed to establish how this structure manifests across diverse STEM learning environments, learner populations, and technological systems. Future research might productively examine: the phenomenology of student experience with learning analytics and AI-generated feedback; the conditions under which human knowledge mediators reproduce or disrupt data subject consciousness in educational contexts; the design features of data systems that support learner epistemic participation; and how resource constraints compound data subject consciousness across differently resourced school systems.

Conclusion

This phenomenological study has introduced data subject consciousness as a concept with direct relevance to STEM education, educational technology design, and learning analytics research. Through intensive analysis of one learner's experience navigating a data-rich technological environment, elite sports science, five themes illuminate how measurement without interpretive access constructs an epistemological condition that is increasingly common across educational contexts. Data opacity, the displacement of embodied knowing by objective measurement, hermeneutic gatekeeping, the wearable paradox, and differential resource access collectively reveal how pervasive measurement systems construct learners as data sources rather than epistemic participants.

The concept matters for STEM education because it names what has been happening to learners in technology-mediated environments without adequate theoretical vocabulary. Students navigating learning analytics systems,

teachers implementing AI-generated instructional recommendations, and learners whose educational trajectories are shaped by algorithmic outputs they cannot interrogate are all experiencing forms of data subject consciousness. That this condition has not been named does not mean it is not operating. This study provides the name and the framework.

Marina's journey from athlete to sports scientist demonstrates that data subject consciousness is not inevitable. It is a structural effect of how institutions organize interpretive access, and it dissolves when learners gain the conceptual resources to interpret their own data environments. STEM education has a particular stake in this dissolution: a field committed to developing scientific reasoning and data literacy cannot afford to leave its own learners as data subjects who cannot read the systems that measure them. The question is whether we will design educational technology that produces epistemic participants or epistemic dependents. Data subject consciousness makes clear what is at stake in that design choice.

References

Akenhead, R., & Nassis, G. P. (2016). Training load and player monitoring in high-level football: Current practice and perceptions. *International Journal of Sports Physiology and Performance, 11*(5), 587-593. https://doi.org/10.1123/ijspp.2015-0331

Allen-Collinson, J. (2009). Sporting embodiment: Sports studies and the (continuing) promise of phenomenology. *Qualitative Research in Sport and Exercise, 1*(3), 279-296. https://doi.org/10.1080/19398440903192340

Baek, Y., Min, E., Yun, S., & Saad, M. (2023). Computer science framework to teach community-based environmental literacy and data literacy to diverse students. *Journal of Research in Science Teaching, 60*(4), 812-843. https://doi.org/10.1002/tea.21826

Clandinin, D. J., & Connelly, F. M. (2000). *Narrative inquiry: Experience and story in qualitative research.* Jossey-Bass.

Dale, G. A. (1996). Existential phenomenology: Emphasizing the experience of the athlete in sport psychology research. *The Sport Psychologist, 10*(4), 307-321. https://doi.org/10.1123/tsp.10.4.307

Dreyfus, H. L. (2002). Intelligence without representation: Merleau-Ponty's critique of mental representation. *Phenomenology and the Cognitive Sciences, 1*(4), 367-383. https://doi.org/10.1023/A:1021351606209

EDUCAUSE. (2022). *2022 EDUCAUSE Horizon Report: Data and analytics edition.* EDUCAUSE. https://www.educause.edu/horizon-report-da

EDUCAUSE. (2024). *2024 EDUCAUSE Horizon Report: Teaching and learning edition.* EDUCAUSE. https://www.educause.edu/horizon-report-tl

EDUCAUSE. (2025). *EDUCAUSE Horizon Action Plan: Supporting agency, trust, transparency, and involvement.* EDUCAUSE. https://www.educause.edu/horizon-action-plan

Foucault, M. (1975). *Discipline and punish: The birth of the prison.* Vintage Books.

Fricker, M. (2007). *Epistemic injustice: Power and the ethics of knowing.* Oxford University Press.

Gould, R. (2017). Data literacy is statistical literacy. *Statistics Education Research Journal, 16*(1), 22-25. https://doi.org/10.52041/serj.v16i1.209

Hockey, J., & Allen-Collinson, J. (2007). Grasping the phenomenology of sporting bodies. *International Review for the Sociology of Sport, 42*(2), 115-131. https://doi.org/10.1177/1012690207078459

Hooshyar, D., Pedaste, M., Yang, Y., Malva, L., Hwang, G.-J., & Huang, R. (2025). Towards responsible AI for education: Mapping challenges and interventions across transparency, accountability, privacy, safety, and ethics. *Computers and Education: Artificial Intelligence, 8*, 100318. https://doi.org/10.1016/j.caeai.2025.100318

Ihde, D. (1990). *Technology and the lifeworld: From garden to earth.* Indiana University Press.

Jin, Y., Echeverria, V., Pijeira-Diaz, H. J., Haataja, E., Malmberg, J., & Järvelä, S. (2024a). FATE in MMLA: A student-centred exploration of fairness, accountability, transparency, and ethics in multimodal learning analytics. *British Journal of Educational Technology, 55*(2), 441-461. https://doi.org/10.1111/bjet.13393

Jin, Y., Echeverria, V., & Järvelä, S. (2024b). Chatting with a learning analytics dashboard: Understanding student experiences with chatbot-assisted dashboards. *Computers & Education, 210*, 104953. https://doi.org/10.1016/j.compedu.2023.104953

Johnston, H., & Jendoubi, H. (2024). Evaluating pedagogical incentives in undergraduate computing: Combining learning analytics with student perspectives. *Journal of Learning Analytics, 11*(1), 55-72. https://doi.org/10.18608/jla.2024.7996

Jones, B., & Sheffield, D. (2019). Modern pentathlon: An example of effective athlete monitoring in a multi-disciplinary sport. *International Journal of Sports Physiology and Performance, 14*(8), 1034-1038. https://doi.org/10.1123/ijspp.2018-0525

Kaliisa, R., Misiejuk, K., Lopez-Pernas, S., Khalil, M., & Saqr, M. (2023). Have learning analytics dashboards lived up to the hype? A systematic review of impact, limitations, and the road ahead. *British Journal of Educational Technology, 54*(5), 1184-1207. https://doi.org/10.1111/bjet.13338

Makar, K., & Rubin, A. (2009). A framework for thinking about informal statistical inference. *Statistics Education Research Journal, 8*(1), 82-105. https://doi.org/10.52041/serj.v8i1.457

Mandinach, E. B., & Gummer, E. S. (2016). What does it mean for teachers to be data literate? *Teaching and Teacher Education, 60*, 366-376. https://doi.org/10.1016/j.tate.2016.07.011

Mears, S. A., Dickinson, K., Bergin, K., Colley, S., & Nevill, A. M. (2019). Monitoring of sleep and rest-activity in relation to recovery in soccer players. *Science and Medicine in Football, 3*(1), 10-17. https://doi.org/10.1080/24733938.2018.1508394

Merleau-Ponty, M. (1962). *Phenomenology of perception.* Routledge.

Moustakas, C. (1994). *Phenomenological research methods.* Sage.

Ngoon, T. J., McKenzie, G., Martelaro, N., & Hammer, J. (2024). ClassInSight: Exploring design opportunities for classroom analytics to support teacher reflection on instructional discourse in high school science. *ACM CHI Conference on Human Factors in Computing Systems*, 1-20. https://doi.org/10.1145/3613904.3642154

Pope, L., Marques, B., & Popescu, A. (2024). An educational tool for learning about social media tracking, profiling, and recommendation. *Computers & Education, 211*, 104990. https://doi.org/10.1016/j.compedu.2023.104990

Postma, W. M., & Dees, M. (2024). Data-driven decision making in sport: Lessons from the football pitch. *Journal of Applied Sport Psychology.* Advance online publication. https://doi.org/10.1080/10413200.2024.2318765

Prinsloo, P., & Slade, S. (2017). An elephant in the learning analytics room: The obligation to act. In *Proceedings of the Seventh International Learning Analytics & Knowledge Conference* (pp. 46-55). Association for Computing Machinery. https://doi.org/10.1145/3027385.3027406

Robertson, S., Bartlett, J. D., & Gastin, P. B. (2017). Red, amber, or green? Athlete monitoring in team sport. *International Journal of Sports Physiology and Performance, 12*(Suppl 2), S2-73-S2-79. https://doi.org/10.1123/ijspp.2016-0410

Roth, W.-M., & Roychoudhury, A. (1993). The development of science process skills in authentic contexts. *Journal of Research in Science Teaching, 30*(2), 127-152. https://doi.org/10.1002/tea.3660300204

Siemens, G. (2013). Learning analytics: The emergence of a discipline. *American Behavioral Scientist, 57*(10), 1380-1400. https://doi.org/10.1177/0002764213498851

Tadimalla, S., & Maher, M. L. (2024). AI literacy for all: Adjustable interdisciplinary socio-technical curriculum for teaching AI literacy in higher education. *International Journal of Artificial Intelligence in Education, 34*(2), 451-479. https://doi.org/10.1007/s40593-023-00357-x

van Manen, M. (2016). *Researching lived experience: Human science for an action sensitive pedagogy* (2nd ed.). Routledge.

Varela, F. J., Thompson, E., & Rosch, E. (1991). *The embodied mind: Cognitive science and human experience.* MIT Press.

Vartiainen, H., Tedre, M., & Kahila, J. (2025). Classroom activities and new classroom apps for enhancing children's understanding of social media mechanisms. *Computers & Education, 224*, 105149. https://doi.org/10.1016/j.compedu.2024.105149

Verbeek, P.-P. (2005). *What things do: Philosophical reflections on technology, agency, and design.* Pennsylvania State University Press.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes.* Harvard University Press.

Zhou, Q., Suraworachet, W., & Cukurova, M. (2024). Harnessing transparent learning analytics for individualized support in collaborative learning environments. *IEEE Transactions on Learning Technologies, 17*, 412-425. https://doi.org/10.1109/TLT.2023.3339217

Corresponding Author Contact Information:

Author name: Joshua Jonas

Department: Curriculum and Instruction

University, Country: Baylor University, USA

Email: joshua_jonas1@baylor.edu

Please Cite: Jonas, J. M. (2026). Measured Without Meaning: Data Subject Consciousness in Technology-Mediated STEM Learning Environments. *Journal of Research in Science, Mathematics and Technology Education*. *9*(3), 95-110. https://doi.org/10.31756/jrsmte.514SI

Conflict of Interest: The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Data Availability Statement: The data supporting the findings of this study consist of interview transcripts containing personally identifiable information. In accordance with the participant's right to confidentiality and consistent with the study's IRB determination (Baylor University IRB Reference #2408191, March 4, 2026), these data are not publicly available. De-identified information may be made available upon reasonable request to the corresponding author.

Ethics Statement: This study received a formal determination of non-human subjects research from the Institutional Review Board at Baylor University (IRB Reference #2408191, March 4, 2026), pursuant to 45 CFR 46.102(e) and (l). Informed consent was obtained from the participant prior to data collection, and the participant is identified by pseudonym throughout to protect confidentiality.

Author Contributions: Joshua M. Jonas conceptualized the study, designed the methodology, conducted the interview and phenomenological analysis, developed the theoretical framework, and wrote and the manuscript.

Received: March 31, 2026 ▪ Accepted: June 7, 2026