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Designing physics instruction around technological breakdown: A DLP projector case

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ABSTRACT

Classroom technologies are generally regarded as impartial instruments for facilitating instruction, whereas their malfunctions are perceived as disturbances to be mitigated. This research contests conventional orientation by providing and assessing an instructional design that intentionally utilizes technological failure as a foundation for physics education. The design is located within a university course for pre-service primary educators and focuses on a defective digital light processing projector that exhibits persistent white dots due to immobilized micromirrors. The instructor utilized the malfunction as a central phenomenon for a series that facilitated observation, hypothesis formulation, representational tasks, and mechanistic elucidation. This research utilizes design-oriented analysis and micro-analysis of classroom interaction to record the evolution of students' thinking from phenomenological descriptions to causal, model-based explanations that connect macroscopic picture artifacts to microscopic physical mechanisms. Concurrently, students' epistemological framing of technology transitioned from black-box perceptions to more analytical, system-oriented viewpoints, accompanied by elevated levels of engagement and curiosity. The paper elucidates the pedagogical rationale of the design, analyzes its implementation in practice, and extracts transferable design principles for instruction amid technological failure. It contends that failures in routine classroom technologies can serve as significant epistemic resources, facilitating genuine inquiry, mechanistic reasoning, and pedagogical creativity. The implications for physics education, teacher training, and the development of inquiry-based professional vision are examined.

Keywords: physics education, instructional design, technological breakdown, teacher education, mechanistic reasoning

INTRODUCTION

Classroom technologies are integral to modern teaching methods, facilitating presentation, visualization, and engagement at all educational levels. Projectors, interactive whiteboards, and digital displays are commonly employed as infrastructural aids, anticipated to operate dependably and to stay predominantly unobtrusive during instructing. When these technologies malfunction, the prevailing educational instinct is to promptly restore functionality to maintain the continuity of the lesson. Breakdowns are perceived as disruptions, sources of frustration, and threats to classroom stability. In teacher education, technological malfunctions are frequently perceived as issues of classroom management rather than as possible learning opportunities.

This attitude is problematic from the perspectives of physics education and didactics. Technological systems are not impartial conduits; rather, they are tangible manifestations of physical laws, design choices, and limitations. Their operation is regulated by optics, mechanics, thermodynamics, and materials science, with failures similarly rooted in physical processes. In the majority of classrooms, pupils are encouraged to utilize technology without being prompted to comprehend them. This reinforces a black-box perspective of technology, wherein devices are regarded as opaque, seamless, and fundamentally beyond the scope of scientific elucidation (de Vries, 2005; Hsu & Ching, 2020). This position contradicts the emphasis in science education on highlighting the materiality of phenomena and involving learners in genuine sense-making (Nachtigall et al., 2024; Yonai et al., 2024).

Genuine learning has been extensively promoted as a method for linking academic science with practical applications and phenomena in the real world. Nonetheless, authenticity is frequently pursued via meticulously crafted contexts and simulations, whereas genuine phenomena that already exist in classrooms are largely underutilized. Technological failures constitute a notably significant and underutilized category of such events. When a device malfunctions in a conspicuous and perplexing manner, routine engagement is interrupted, resulting in a legitimate problem area. Students observe, remark, and hypothesize. Inquiries emerge spontaneously. The scenario is unscripted, and the rationale is not provided beforehand. In this context, breakdowns can produce a profound authenticity, rooted in tangible material limitations rather than solely in pedagogical design (Herrington et al., 2014; Nachtigall et al., 2024). While physics education research has long employed discrepant events, anomalies, and unexpected experimental outcomes as resources for inquiry, these have typically been designed or staged in advance. The present work extends this tradition by examining an unscripted technological failure arising from routine classroom infrastructure, thereby reframing breakdown not as a pedagogical device introduced by the teacher, but as a naturally occurring phenomenon appropriated for instructional purposes.

This paper introduces and examines an instructional design that intentionally utilizes technological breakdown as a foundation for physics education. The design focuses on a defective digital light processing (DLP) projector that exhibited a persistent white dot pattern caused by immobilized micromirrors. The instructor utilized this dysfunction as the central phenomenon for a series of activities designed to facilitate observation, hypothesis formulation, modelling, and mechanistic elucidation. This study examines an instructional design that treats technological breakdown as a starting point for physics inquiry. The context is a university course for pre-service primary teachers in which a malfunctioning DLP projector served as the central phenomenon for observation, hypothesis generation, and modelling.

The study is guided by the following research questions (RQs):

- **RQ1.** How does an instructional sequence organized around a technological malfunction support students' development of mechanistic explanations connecting observable effects to underlying physical mechanisms?
- **RQ2.** How do students' epistemic framings of everyday technology evolve as they engage with the malfunction as a phenomenon to be explained?
- **RQ3.** What instructional moves and representational resources support this transition during classroom interaction?

The paper proceeds in three steps. First, it articulates the design rationale for treating technological breakdown as an epistemic resource for inquiry. Second, it documents the empirical enactment of the design through micro-analysis of classroom interaction. Third, it derives design implications for physics instruction and teacher education from the case.

Rather than claiming general effectiveness, the purpose of the study is analytic: to illuminate how a particular instructional design unfolds in practice and how students' reasoning develops in relation to it. It contends that technological failure ought to be regarded not as a source of shame to conceal, but as an educational asset to be cultivated

While physics education research has long used discrepant events and anomalies as catalysts for inquiry, these events are typically deliberately staged by instructors or embedded in experimental setups. The present study extends this tradition by examining a different category of phenomenon: technological breakdowns arising from routine classroom infrastructure. Rather than designing an anomaly for pedagogical purposes, the instructor appropriates an unscripted malfunction and treats it as the central phenomenon for inquiry. In this sense, technological breakdown is conceptualized not as a teacher-constructed discrepant event but as a naturally occurring material phenomenon whose explanation emerges through classroom interaction. The study therefore contributes to research on inquiry and authenticity by examining how an everyday technological failure can function as an epistemic resource for mechanistic reasoning and epistemic reframing.

DESIGN RATIONALE

This paper's instructional design is based on the notion that technological failure can serve as a productive epistemic resource for learning. This premise is based on the integration of insights from engineering studies, the philosophy of technology, and research in science education. In engineering, failure is acknowledged as a fundamental source of information. Examinations of collapsed structures, shattered components, and malfunctioning systems have traditionally propelled advancements in design and theory. Petroski (2012) contends that comprehending the reasons for failure is frequently more enlightening than grasping the reasons for functionality, as failure exposes the assumptions, limits, and weaknesses inherent in designs. From this viewpoint, breakdown is not an unpleasant anomaly but an inherent characteristic of modern systems.

Translating this knowledge into educational terminology indicates that technological breakdown can serve as a valuable opportunity for learning. When a device operates seamlessly, its internal intricacies are obscured, rendering its functionality routine and epistemically imperceptible. When it malfunctions, its physicality is emphasized. A previously transparent object becomes opaque. Focus is directed towards structure, mechanism, and causality. In a classroom, such instances can foster an environment for inquiry that is challenging to replicate artificially. Research on authenticity corroborates this perspective, highlighting that learning attains significance when students interact with phenomena that are not entirely scripted and whose explanations remain undetermined. In contrast to intentionally staged discrepant events, the breakdown examined here was not designed as an anomaly but originated from the routine material infrastructure of the classroom. Technological breakdowns therefore carry a distinctive epistemic status: they resist anticipation, control, and optimization, and thus demand genuine sense-making from both students and instructors (Nachtigall et al., 2024; Yonai et al., 2024).

The design reasoning is influenced by constructivist and inquiry-based approaches to learning. Research on problem-based and inquiry learning indicates that students are more inclined to engage profoundly when faced with perplexing, ill-structured phenomena that defy immediate elucidation (Hmelo-Silver et al., 2007). At the core of these methodologies is the concept of epistemic ownership, wherein learners perceive the problem as authentically their own rather than merely an assignment from the instructor. The current design presents the technological breakdown not as a pedagogical illustration but as an authentic and initially inexplicable occurrence. This fosters a sense of ownership and designates students as sense-makers instead of mere answer-seekers.

Another design concept pertains to the teacher's epistemic restriction. Conventional teaching frequently entails swift elucidation and identification, wherein educators promptly classify events and deliver authoritative narratives. This practice, although efficient, may undermine students' sense-making and diminish opportunities for mechanistic reasoning. The design intentionally postpones technical explanation, prioritizing opportunities for observation, description, hypothesis formulation, and representation. This corresponds with research on productive disciplinary engagement, which underscores the significance of positioning students as authors of ideas and contributors to knowledge construction rather than as passive recipients (Chinn et al., 2011; Windschitl et al., 2008).

The design is fundamentally based on the significance of diverse representations and micro-macro coordination. Comprehending technological systems generally necessitates correlating macroscopic characteristics with microscopic structure and processes. Studies on learning with multiple representations indicate that coordination does not happen autonomously but requires deliberate instructional sequencing (Ainsworth, 2006; Treagust et al., 2017). In the DLP case, students transition between the visible image on the screen, diagrams of the optical pathway, and schematic illustrations of micromirror functionality. Each representation emphasizes distinct facets of the system, and the educational objective is to assist students in integrating them into a cohesive causal model.

The design reasoning is ultimately influenced by factors pertinent to teacher education. Pre-service teachers are acquiring knowledge of physics as well as pedagogical methods for teaching it. Their experiences as learners shape their professional vision and their perception of what constitutes a legitimate teaching moment (Grossman et al., 2009; Korthagen, 2010). By involving them in an investigation of an actual technological failure, the design exemplifies an approach to classroom occurrences that prioritizes curiosity, adaptability, and responsiveness. The teacher perceives faults not as threats to authority, but as possibilities for learning. This modeling constitutes a potent method of pedagogy.

Collectively, these factors culminate in a design that regards technological failure as an epistemic asset, emphasizes student comprehension, meticulously organizes representations, and highlights the materiality of technology. The subsequent sections delineate the translation of this rationale into an instructional sequence and its implementation in classroom practice.

Three theoretical constructs guide the analysis in this study. Mechanistic reasoning refers to explanations that identify entities, activities, and causal relationships connecting microscopic mechanisms to macroscopic phenomena. Epistemic framing concerns how students interpret the nature of the task and what counts as a legitimate form of explanation within the classroom activity. Authenticity is understood relatively, emerging when learners engage with phenomena that are materially real and whose explanations are not predetermined. In the analysis that follows, these constructs serve as analytic lenses for interpreting how students' reasoning develops as they interact with the technological breakdown.

CONTEXT AND LEARNERS

The instructional design was executed within a university course focused on physics teaching for pre-service primary educators. The course constitutes a component of a four-year teacher education curriculum and is undertaken in the third year, subsequent to the completion of foundational coursework in general education, psychology, and fundamental science. The primary objectives are to enhance conceptual comprehension of physical phenomena pertinent to the primary curriculum and to foster pedagogical methods rooted in inquiry, explanation, and sense-making. The course emphasizes assisting prospective educators in transcending procedural tasks to comprehend physics as a means of comprehending the physical world. This stance aligns with modern methodologies in teacher education that emphasize the amalgamation of topic knowledge and pedagogical reasoning instead of considering them as distinct areas (Grossman et al., 2009; Korthagen, 2010).

The intervention involved 34 pre-service teachers, predominantly female, mirroring the demographics of the primary education program. The majority possessed less formal education in physics beyond mandatory secondary schooling and expressed poor confidence in their physics expertise at the course's outset. Prior studies have indicated that pre-service primary educators commonly possess tenuous or disjointed comprehensions of physical concepts and frequently encounter anxiety or diminished self-efficacy concerning physics (Appleton, 2003; Mulholland & Wallace, 2001). Affective and epistemic dispositions significantly shape the learning context, impacting students' engagement with unfamiliar phenomena and open-ended inquiry.

Participants exhibited a profound familiarity with digital devices as users. They consistently utilized smartphones, laptops, and projectors in their academic pursuits and daily activities. Nonetheless, as is prevalent in modern digital culture, their familiarity was primarily functional rather than structural. They possessed the ability to operate technology but lacked understanding of their internal mechanisms. This pattern illustrates wider trends observed in studies on technology utilization in education, wherein both students and educators often regard devices as opaque entities, concentrating on superficial functionality rather than underlying mechanisms (de Vries, 2005; Hsu & Ching, 2020). The coexistence of functional familiarity and structural opacity presents a complex yet advantageous environment for teaching that seeks to uncover the physics inherent in common technologies.

The physical environment consisted of a conventional university classroom featuring immovable seating, a ceilingmounted DLP projector, and an expansive projection screen. The projector had a distinct pattern of enduring white dots observable across all projected material and within the device's internal menu. This issue had persisted for an extended period and was acknowledged by both personnel and students. Typically, it would have been sent for repair or replacement. In this instance, the instructor intentionally opted to keep the defective item to utilize it as a central phenomenon for educational purposes. The decision was clearly conveyed to the pupils, framing the breakdown not as oversight but as a deliberate educational strategy. This transparency is crucial for sustaining trust and exemplifying an inquiry-based approach to classroom occurrences (Korthagen, 2010).

The dual identity of the learners as students and prospective educators is crucial for comprehending the dynamics of the intervention. They treated the phenomenon like learners aiming to comprehend a novel physical system. Conversely, they were concurrently contemplating, either implicitly or openly, how analogous circumstances may be managed in their prospective classrooms. Studies on teacher education indicate that dual positioning can be beneficial, enabling pre-service teachers to link content acquisition with pedagogical creativity (Grossman et al., 2009). Nonetheless, it also engenders tensions, as students may be apprehensive about classroom management, authority, and control, even while participating in inquiry. These tensions constitute the context in which the design functions.

The course prioritized culture dialogue, inquiry, and collective understanding. Students were familiar with collaborating in small groups, publicly exchanging ideas, and participating in exploration discussions. This cultural context is crucial, as inquiry-based designs depend on norms that appreciate uncertainty, incomplete concepts, and collaborative reasoning (Windschitl et al., 2008). In transmission-focused contexts, technological failures may be perceived chiefly as a disruption to lesson continuity and teacher authority. In this context, the prevailing norms of discourse and contemplation fostered a collaborative atmosphere for addressing the dysfunction as a collective issue rather than an individual shortcoming.

Simultaneously, it is crucial to acknowledge that the situation was not artificially fabricated for study objectives. The failure was authentic, the apparatus was truly defective, and the limitations of time, curriculum, and institutional environment were characteristic of typical university instruction. The ecological validity is fundamental to the study's design rationale. The objective was not to evaluate an intervention under optimal conditions but to investigate how a genuine technology flaw may be pedagogically utilized in situ. This approach corresponds with the recommendations in design-based research to engage with, rather than oppose, the intricacies of educational environments (Design-Based Research Collective, 2003).

The intervention environment had learners with low confidence in physics yet considerable technological proficiency, an inquiry-supportive classroom culture, and a noticeable, persistent technological problem. These features collectively established an environment where technological failure could feasibly be reconceptualized as a learning opportunity. At the same time, they delineate important boundary conditions for the design. The approach presupposes norms that tolerate uncertainty, instructional time that allows exploratory discussion, and an instructor willing to temporarily suspend immediate problem resolution. Grasping this context is therefore crucial not only for interpreting the instructional design and its implementation, but also for evaluating the conditions under which similar designs may or may not be productive in other educational settings.

INSTRUCTIONAL DESIGN

This study adopts a design-oriented research perspective that focuses on understanding how instructional intentions, material conditions, teacher actions, and student sense-making interact during classroom activity. The purpose is not to evaluate the effectiveness of an intervention through predefined outcome measures, but to articulate and analyze the instructional logic of a design as it unfolds in practice.

Empirical material consisted of video recordings of two consecutive 90-minute class sessions, complemented by field notes and written artifacts produced by students during individual and group work. The classroom episode selected for micro-analysis was chosen because it captured a salient shift in students' explanatory reasoning following the introduction of a representational model of the DLP projector.

The analysis draws on micro-analytic approaches commonly used in physics education research to examine discourse, gesture, and representational activity in situ. All participants provided informed consent for video recording and research use of classroom data in accordance with institutional ethical guidelines. Students were informed that participation in the study was voluntary and that anonymized excerpts of interaction and written work could be used for research purposes. Pseudonyms are used throughout the analysis.

Analytic Procedure

The analytic process followed an iterative and abductive approach typical of design-oriented classroom studies. Initial viewing of the video corpus was used to identify episodes in which students attempted to account for the projector malfunction. Episodes were then examined through repeated viewing and transcript analysis, focusing on the coordination of discourse, gesture, and reference to representations. Analytical attention was guided by theoretical constructs including mechanistic reasoning, epistemic framing, and micro-macro coordination, while remaining open to emergent patterns in students' explanations. Video, transcripts, and written artifacts were examined in parallel to trace how students' ideas developed across interactional turns and representational resources.

Video recordings were transcribed verbatim, including relevant pauses, overlaps, and notable gestures when these contributed to meaning making. Transcripts were synchronized with video to allow repeated inspection of talk, gesture, and reference to material representations such as the screen and diagrams.

The primary unit of analysis was the interactional episode, defined as a coherent segment of classroom discourse organized around a specific explanatory problem. Episodes were initially segmented through repeated viewing of the recordings, focusing on moments in which students attempted to account for the white dots observed in the projection.

One episode was selected for detailed micro-analysis because it contained a clear transition from phenomenological descriptions to mechanistic explanation following the introduction of the micromirror representation. To reduce confirmation bias, the selection was based on two criteria:

(a) the presence of sustained student-led reasoning about the phenomenon and

(b) the explicit coordination of the representation with the observable effect on the screen.

Analysis proceeded iteratively. First, transcripts were examined to identify moments in which students proposed explanations, questioned representations, or linked macroscopic observations to internal mechanisms. Second, these moments were analyzed using conceptual lenses drawn from research on mechanistic reasoning, epistemic framing, and micro-macro coordination. Third, video was revisited to examine how gestures, pointing, and references to representations supported the development of explanations.

Trustworthiness was supported through repeated viewing of the video corpus, triangulation of video, field notes, and student artifacts, and the use of extended transcript excerpts to allow readers to examine the empirical grounding of interpretations.

Analytical attention was directed toward the development of mechanistic reasoning, the coordination of micro-macro representations and shifts in students' epistemic framing of technology and explanation. The educational design was developed as a brief yet intensive sequence centered on the malfunctioning DLP projector as a consistent, communal phenomenon. The fundamental approach was to permit the breakdown to create the epistemic necessity for explanation, rather than presenting the physics content as a preordained subject. The design adheres to a phenomenon-first rationale, wherein observation and inquiry precede conceptualization (Hmelo-Silver et al., 2007). The sequence unfolded across two successive 90-minute sessions and was structured to facilitate a progression from observation to description, from description to hypothesis formulation, and from hypothesis to modeling and explanation.

The initial session commenced with intentional epistemic restriction. The instructor failed to specify the technology or offer any technical elucidation. Students were invited to scrutinize the projected image and articulate their observations. They were instructed to observe the color, size, shape, distribution, and stability of the white dots and to document any alterations when the background color, brightness, or input source was modified. This initial phase aimed to emphasize observation as a valid epistemic activity and to mitigate the prevalent inclination to hastily go to explanation. Studies on inquiry learning indicate that meticulous focus on phenomena is an essential although frequently overlooked component of sense-making (Hammer, 1995; Hmelo-Silver et al., 2007). The design sought to foster an evidence-based orientation by decelerating the interaction and validating description, rather than promoting rapid categorization.

Initially, students worked independently, documenting their observations in writing, before engaging in discussions within small groups. This arrangement was deliberate. Solo work allowed each student to observe and express characteristics independently, free from peer influence, whereas group discussions facilitated comparison, negotiation, and enhancement of concepts. The instructor moved among the students, listening and intermittently posing clarifying questions, while refraining from providing evaluative feedback. This position is consistent with research on productive disciplinary engagement, highlighting the significance of positioning students as authors of ideas and preserving epistemic authority within the learning community (Chinn et al., 2011).

After the observations were disseminated, students were encouraged to formulate potential explanations. At this juncture, all hypotheses were accepted and documented publicly, encompassing those related to dust, software malfunctions, corrupted files, and signal issues. The design intentionally refrained from filtering or rectifying these concepts. This transparency fulfilled two purposes. Initially, it externalized students' preliminary notions, rendering them accessible for communal examination. Secondly, it conveyed that the explanation was tentative and open to modification. Studies on conceptual change indicate that articulating learners' concepts is essential for facilitating their transformation (Chi, 2005; Vosniadou, 2013). The design aimed to establish an epistemically secure environment by recognizing all contributions as valid starting points, thereby permitting uncertainty and partial comprehension.

A significant design decision during this phase was the implementation of constraints. Instead of informing students about the incorrect explanations, the instructor encouraged them to evaluate their hypotheses against the phenomenon. For instance, when software or file-based explanations were suggested, emphasis was placed on the enduring presence of the dots in the projector's internal menu. Upon the suggestion of dust, students were instructed to evaluate the acuity and luminosity of the dots. This technique demonstrates a dedication to understanding through evidence rather than reliance on authority. It corresponds with inquiry methodologies that highlight the significance of anomalies and counterevidence in facilitating conceptual enhancement (Lombardi, 2007).

The second session signified a shift from hypothesis generation to modeling. At this juncture, simplified depictions of the projector's optical pathway and a digital micromirror device were presented. The timing was intentional. Representational tools were offered only when students experienced confusion and attempted to explain. This sequencing aligns with research on multiple representations, which warns that such representations are most effective when learners have a purpose for utilizing them and a relevant problem to address (Ainsworth, 2006; Treagust et al., 2017). The representations were schematic, emphasizing fundamental relationships without inundating pupils with technical intricacies.

Students were instructed to collaborate in small groups to analyze the diagrams and correlate them with their findings. The objective was to create causal connections connecting the observable white dots to potential internal mechanisms. The instructor's role was to elicit, interrogate, and rearticulate rather than to elucidate. Inquiries like, "What must occur internally for this dot to consistently emit brightness?" "Which component of this diagram may be accountable for that?" were employed to direct attention while maintaining open possibilities. This method is based on studies regarding scaffolding in inquiry learning, highlighting the importance of contingent support that addresses learners' ideas instead of supplanting them (Hmelo-Silver et al., 2007).

A crucial representational strategy in the design was the incorporation of the micromirror as a tangible item capable of tilting and directing light. This was a time of significant conceptual and emotional effect for many kids. The concept of millions of minuscule mirrors operating within the projector contested their conventional beliefs regarding digital images and incited a plethora of inquiries. Instead of promptly delivering a comprehensive technical explanation, the lecturer encouraged students to engage with the model, prompting them to contemplate the implications of an immobile mirror. This promoted mechanistic reasoning, wherein students recognized entities, activities, and interactions (diSessa, 2007). The white dots could now be understood not as abstract "pixels" but as the optical effects of specific physical components fixed in a particular position.

During this phase, emphasis was placed on micro-macro coordination. Students were consistently encouraged to connect the microscopic movement of mirrors to the macroscopic visual representation of the image. This is a well-documented issue in physics teaching, since students frequently find it difficult to associate unseen mechanisms with observable outcomes (Chi, 2005; Vosniadou, 2013). The design resolved this by alternating between the screen and the diagrams, prompting students to indicate, gesture, and articulate the links. Embodied and multimodal strategies are recognized for enhancing representational competence and conceptual integration (Tytler et al., 2013).

An important pedagogical decision was to leave certain questions intentionally unresolved. For instance, although students were instructed that mirrors may become immobilized, comprehensive discourse on fatigue, adhesion, or dielectric breakdown was restricted. This was a deliberate choice to prevent the session from becoming a brief lecture on MEMS dependability. The objective was not comprehensive technical analysis but rather the formulation of an explanatory perspective. Investigations into inquiry-based learning indicate that the profundity of reasoning supersedes the extent of content, especially during brief interventions (Hmelo-Silver et al., 2007; Windschitl et al., 2008). By leaving certain mechanisms unspecified, the design maintained the perception of technology's complexity and the potential for continual refinement of explanations.

The concluding phase of the process encompassed contemplation and generalization. Students were encouraged to contemplate the applicability of analogous reasoning to other technologies and how they might integrate such scenarios into their own pedagogy. This action facilitated the integration of content acquisition with educational creativity. Studies on teacher education have highlighted the necessity of enabling pre-service teachers to perceive themselves as architects of learning experiences rather than mere transmitters of knowledge (Grossman et al., 2009; Korthagen, 2010). The design aimed to exemplify a responsive and creative approach to unanticipated events by directly prompting students to consider the pedagogical applications of breakdowns.

The instructor's position was a vital component of the design throughout all phases. Authority was exerted not by elucidation but through the orchestration of activities, management of time, and structuring of tasks. This corresponds with modern perspectives on teaching as the design and management of learning environments rather than the mere transmission of knowledge (Windschitl et al., 2008). The malfunction of the projector was regarded not as an issue to be resolved, but as a phenomenon to be comprehended. This framing was conveyed through language, tempo, and the explicit choice to forgo speedy rectification. The design engaged students in inquiry while also exemplifying an epistemic approach to technology and pedagogy.

In summary, the instructional design exhibited a phenomenon-first approach, epistemic restraint, meticulous sequencing of representations, and a dedication to student comprehension. The design established a coherent learning trajectory by organizing activities around a genuine technological failure, progressing from observation to mechanistic explanation and from content comprehension to pedagogical reflection. This section analyzes a particular classroom episode to demonstrate the implementation of this design in interaction and the progression of students' reasoning over time.

MICRO-ANALYSIS OF A CLASSROOM EPISODE

This section provides a micro-analysis of a classroom episode from the second session, during which the micromirror model was initially introduced, to demonstrate the implementation of instructional design and the progression of students' thinking in real-time. Micro-analytic methodologies are extensively employed in physics education research to investigate the intricate dynamics of sense-making, epistemic framing, and conceptual transformation during interactions (diSessa, 2007; Hammer & Berland, 2014). The episode was chosen as it illustrates a discernible transition in students' reasoning from phenomenological description to mechanistic explanation, highlighting how teacher interventions and peer interactions facilitated this shift.

At the episode's outset, students had determined that the white dots originated from within the projector, rather than from the computer or the signal. Nonetheless, their elucidations remained ambiguous. One student posited that "something internal is fractured and no longer evolves," while another suggested that "the illumination must be more intense in those areas." These assertions reflect a developing internal attribution but lack clarity regarding specific entities or mechanisms. From a mechanistic reasoning standpoint, they discern an effect but not a causal framework (Chi, 2005; diSessa, 2007).

The lecturer subsequently displayed a simplified diagram of a DLP optical pathway, illustrating a light source, a micromirror array, and a projection lens. Instead of elucidating the graphic, the instructor inquired, “What do you believe is occurring here?” and indicated the micromirror array. This open prompt designated students as interpreters of representation rather than mere receivers of information. A group of students leaned forward, indicated the diagram, and had a discussion among themselves. One student remarked, “These must be exceedingly small mirrors,” while another inquired, “Do they genuinely move?” The emotional atmosphere at this point changed significantly, accompanied by audible emotions of astonishment and laughing. These reactions are noteworthy, as they signify the activation of situational interest and epistemic curiosity (Hidi & Renninger, 2006; Palmer, 2009).

The instructor verified that the mirrors are capable of tilting and posed the following question:

> Instructor: If each mirror directs light either toward the screen or away from it, what would happen if one of them could no longer move?
>
> (pause)
>
> Student A: Then that point would always send light to the screen.
>
> Student B: So that dot would always stay bright.
>
> Student C: Yes, because the mirror would be stuck in the same position.

This exchange illustrates a transition from earlier descriptions of the dots as a generic “malfunction” toward a mechanistic explanation that identifies an entity (the micromirror), an activity (tilting), and a causal consequence (persistent light on the screen). Students begin to coordinate the microscopic component of the device with the macroscopic visual effect, thereby constructing a causal explanatory chain.

Students transitioned from ambiguous concepts of “something broken” to a causal relationship connecting the immobility of a particular component to the sustained luminosity of a pixel. They identified an entity (the mirror), an activity (tilting or not tilting), and an outcome (light direction), and connected them within a coherent explanatory framework (diSessa, 2007).

The noteworthy aspect of this interaction is that the instructor did not offer the explanation but instead established the conditions for students to formulate it themselves. The inquiry was meticulously constructed to prompt mechanical reasoning without specifying the process. This corresponds with research on scaffolding in inquiry learning, which highlights contingent support that enhances learners’ ideas instead of supplanting them (Hmelo-Silver et al., 2007). The instructor’s indication of the diagram and the formulation of the question focused attention on pertinent aspects while preserving epistemic agency for the students.

Subsequent to this preliminary insight, peer-to-peer elucidation intensified. One student remarked to her neighbor, “Each dot represents a singular mirror that is affixed.” Another responded, “That is astonishing; there are numerous instances of them.” The language employed is noteworthy. The phrases “each dot” and “one mirror” signify a one-to-one correspondence between macroscopic characteristics and microscopic elements. The mapping represents a fundamental challenge in micro-macro coordination and is frequently difficult for learners to accomplish (Chi, 2005; Vosniadou, 2013). The unplanned expression of this relationship indicates that the representational and conversational context facilitated conceptual integration.

The instructor subsequently inquired, “What reasons might cause a mirror to become lodged?” This inquiry broadened the causal chain and prompted students to contemplate material properties and physical limitations. Responses included “perhaps it deteriorates,” “perhaps it becomes soiled,” and “perhaps it overheats.” Although these explanations lacked technical precision, they reflect a developing awareness of material degradation, fatigue, and environmental influences. Significantly, pupils were now contemplating actual processes instead of abstract malfunctions. This transition signifies an epistemological shift towards regarding technology as a material system governed by physical laws, aligning with the advocacy for emphasizing materiality in science education (de Vries, 2005; Hsu & Ching, 2020).

Throughout this interaction, the instructor abstained from providing corrections or elaborations, opting instead to reiterate students’ contributions and inscribe crucial terms on the board. This practice validated students’ ideas and made them publicly accessible for further development. Revoicing is an established discourse approach in scientific classrooms employed to elucidate, validate, and link student contributions (O’Connor & Michaels, 1996). In this instance, it facilitated the development of a collective explanatory framework without enforcing a dominant narrative.

A notably illuminating instance transpired when a student inquired, “Is this physics? Accompanied by laughter.” The instructor inquired, “What is your opinion?” This exchange, albeit succinct, is epistemologically profound. The inquiry implies that the student did not first recognize technological breakdown as pertaining to the field of physics. The instructor’s response delegated the epistemic judgment back to the students, encouraging them to contemplate the limits of the discipline. A number of students responded, “Yes, due to its light and movement,” and “Because it pertains to internal mechanisms.” This signifies an enhancement of their understanding of physics from theoretical principles to the examination of tangible systems. These instances are essential to epistemic framing, as they illustrate how learners are negotiating the criteria for legitimate knowledge and activities within the classroom (Hammer & Berland, 2014; Hammer & Elby, 2002).

The embodied aspect of the relationship warrants consideration. Students consistently indicated the screen, the graphic, and certain dots during their discourse. These movements were not only illustrative; they were essential to the creation of meaning. Studies on multimodal learning indicate that gestures, gaze, and spatial reference are essential for coordinating representations and grounding abstract reasoning (Tytler et al., 2013). This incident allowed students to ground their explanations in perceptual experience through the physical co-presence of the occurrence and its representation.

The emotional atmosphere throughout the program was consistently uplifting and lively. Frequent expressions of astonishment, pleasure, and intrigue were seen. Instead of detracting from learning, these emotions seemed to enhance engagement and diminish the perceived risk of sharing ideas. This corresponds with research on interest and engagement, highlighting that emotional responses can enhance cognitive investment, especially in inquiry contexts (Hidi & Renninger, 2006; Palmer, 2009). The defective projector, rather than eliciting annoyance, sparked communal wonder.

From an educational standpoint, the episode illustrates how a thoughtfully constructed environment can facilitate the development of mechanistic reasoning without explicit teaching. The instructor's responsibility was to facilitate attention, raise thought-provoking questions, and uphold an open epistemic position rather than merely impart knowledge. The representational resources were introduced when students had an epistemic necessity for them, and the physical phenomenon remained observable throughout, grounding the discussion. This array of design elements facilitated a shift from phenomenological to mechanical explanation that would have been challenging to accomplish through lecture alone.

This episode exemplifies how technological failure can serve as a common reference point for collective sense-making. The phenomenon was universally observable and consistently stable, allowing students to revisit it multiple times to test and refine their concepts. This stability is a crucial attribute of numerous technological failures and differentiates them from transient experimental effects. In this context, breakdowns might function as enduring epistemic anchors that facilitate the structuring of inquiry.

The micro-analysis elucidates the implementation of instructional design during interactions and the progression of students' reasoning through dialogue, representation, and embodied engagement. Technological failure can stimulate mechanistic thinking, epistemic reflection, and emotional engagement when facilitated by deliberate education. The subsequent part analyzes the overarching design consequences throughout the sequence, transitioning from moment-to-moment interactions to the overall pedagogical impact.

DESIGN OUTCOMES

The instructional design produced a set of interconnected outcomes that illuminate the educational potential of technological failure as a pedagogical resource. Analytically, these outcomes are organized around three dimensions: the development of mechanistic reasoning, shifts in students' epistemic framing of technology and explanation, and the emergence of pedagogical imagination among pre-service teachers, with engagement functioning as an enabling condition across these processes. A primary outcome was the development of mechanistic reasoning, as students moved from phenomenological descriptions and vague references to "damage" or "malfunction" toward explanations identifying specific entities, activities, and causal relationships. The micromirror thus became a concrete explanatory resource, enabling students to connect the immobility of a physical component with the persistent brightness of a pixel on the screen. This progression aligns with research on the development of mechanistic explanations, highlighting the significance of recognizing underlying structures and processes instead of depending on superficial characteristics (Chi, 2005; diSessa, 2007). The design outcome is not merely that students acquire knowledge about DLP projectors, but that they engaged in a form of reasoning fundamental to physics: constructing explanations that connect macroscopic phenomena to underlying physical mechanisms. Evidence of mechanistic reasoning also appeared in students' written and diagrammatic artifacts. During the second session several groups sketched simplified representations of the projector mechanism while attempting to account for the persistent white dots. One group, for example, drew a grid representing the micromirror array and marked several mirrors as "stuck," connecting them with arrows to corresponding white dots on the screen. The accompanying written explanation stated that "if a mirror cannot tilt away from the light source, that pixel remains permanently bright." These artifacts illustrate how students began to externalize the correspondence between microscopic device components and macroscopic visual effects.

A notable change in epistemic framework was closely associated with this. Initially, numerous students regarded the projector as an enigmatic device and the malfunction as a mere abstract "glitch." By the conclusion of the sequence, students were discussing internal components, material deterioration, and physical limitations. Technology was no longer situated outside the realm of physics but integrated within it. This transition corresponds with studies on epistemic cognition, indicating that learners' views regarding the nature of knowledge and explanation influence their engagement with content (Hammer & Elby, 2002). The design outcome involves the transformation of technology from a mere tool to an object of investigation, and the redefinition of malfunction from a mere inconvenience to a form of evidence.

A third outcome pertains to micro-macro cooperation. Students exhibited an enhanced capacity to correlate observable characteristics of the projected image with the underlying processes of the device. The one-to-one correspondence between white dots and individual micromirrors, once defined, became a reliable explanatory foundation. The coordination of levels presents a well-documented challenge in physics education, especially when addressing scales that exceed direct perception (Treagust et al., 2017; Vosniadou, 2013). The design facilitated this coordination by integrating phenomenon and representation and through their continual oscillation. The result is not merely representational competence but a cohesive explanatory perspective wherein various levels of description are regarded as mutually enlightening.

Engagement and emotional involvement represent a fourth significant consequence. Students exhibited elevated levels of curiosity, astonishment, and prolonged focus during the sequence. The defective projector, rather than causing annoyance, transformed into a collective object of intrigue. This pattern corresponds with theories of situational interest, which assert that novelty, cognitive conflict, and relevance can initiate and sustain engagement (Hidi & Renninger, 2006; Palmer, 2009). The design outcome is the conversion of a potentially adverse classroom event into a beneficial emotional resource. This has significant implications for pedagogical practice, indicating that disruptions can be utilized to invigorate rather than hinder learning.

A notable result in this area is the development of pedagogical reasoning among pre-service instructors. During reflections and discussions, students commenced articulating how analogous situations could be employed in primary classrooms. They observed that youngsters frequently recognize when things malfunction and proposed that these instances could serve as opportunities to teach scientific inquiries. This signifies a transition from perceiving inquiry as learners to envisioning inquiry as educators. Studies on teacher education have consistently demonstrated that the transfer of knowledge is not automatic, and pre-service teachers frequently encounter difficulties in linking university learning to classroom practice (Grossman et al., 2009; Korthagen, 2010). The design outcome is the stimulation of pedagogical imagination, enabling students to perceive routine classroom occurrences as opportunities for instruction rather than challenges to be addressed.

A further significant effect pertains to pupils' relationship with uncertainty. Initially, numerous students pursued immediate solutions and exhibited discomfort with uncertainty. As the sessions advanced, uncertainty became increasingly acceptable and even beneficial. Students demonstrated a willingness to hypothesize, refine their concepts, and accept incomplete explanations. This transition signifies an adoption of an inquiry-oriented epistemic perspective, wherein knowledge is perceived as constructed and subject to revision rather than as predetermined (Chinn et al., 2011; Hammer & Elby, 2002). The design outcome is not merely the acceptance of ambiguity but rather the active engagement with it as a catalyst for sense-making.

The design seemingly impacted pupils' perceptions of pedagogy and authority. The students witnessed the instructor intentionally refraining from repairing the projector and delaying the explanation of the phenomenon, thereby presenting a teaching model that prioritizes exploration over authority. This stands in opposition to prevailing perceptions of education as the seamless presentation of prearranged material. This modeling is especially effective in teacher education, as students' experiences as learners influence their professional identities (Korthagen, 2010). The result is a nuanced yet significant alteration in students' perceptions of valid teaching methodologies.

The design yielded results pertaining to classroom culture. The malfunction served as a common reference point that structured collective thought. Students indicated the screen, elaborated on each other's concepts, and participated in collaborative understanding. This collaborative approach is fundamental to effective disciplinary interaction, highlighting the social aspect of knowledge formation (Windschitl et al., 2008). The design outcome is the creation, if momentarily, of a community of inquiries centered on a genuine and significant issue.

Collectively, these results indicate that the educational significance of the design resides not in any individual effect but in the array of transformations it facilitates. Mechanistic reasoning, epistemic reorientation, and pedagogical imagination emerged as interdependent and mutually reinforcing dimensions of the learning experience. The technological breakdown acts as a catalyst that aligns these dimensions. Instead of dividing learning into distinct cognitive, affective, and pedagogical domains, the design unifies them around a common phenomenon.

This integration is especially significant from a pedagogical standpoint. Physics education frequently fails to integrate conceptual rigor with practical relevance, while teacher education often encounters difficulties in bridging theory and practice. The current design indicates that technological failures can act as connections between these disparities. They are intellectually profound, emotionally compelling, and educationally indicative. The design outcomes suggest a reconsideration of the suitability of everyday classroom activities for learning, while recognizing that such reevaluations depend on pedagogical norms, instructional goals, and the capacity of teachers and learners to engage productively with uncertainty.

DESIGN PRINCIPLES DERIVED

The examination of the educational sequence and its results facilitate the articulation of design concepts that transcend the particular instance of the DLP projector and situate the case within a broader family of physics education designs that leverage unexpected phenomena, anomalies, and material disruptions as resources for inquiry. The principles articulated below should be understood as design orientations rather than procedural steps. They do not prescribe a fixed sequence of actions but highlight considerations that can guide the pedagogical use of technological breakdowns in diverse instructional contexts. These principles are not recipes or methods, but pedagogic orientations that can guide the design of learning environments in which technological breakdowns are treated as epistemic resources. They emerge inductively from the case, while being anchored in established theories and research within physics education, inquiry-based learning, and teacher training.

A primary concept involves the intentional reclassification of technological breakdown from a disruption to a phenomenon. In traditional classroom practice, disruptions are regarded as issues to be resolved or circumvented. The current design intentionally stabilized the malfunction and positioned it as a subject of inquiry. This change in perspective is significant; it represents an epistemic reclassification of the event. The breakdown is recontextualized within the realm of scientific explanation, rather than being associated with logistics or classroom management. This principle aligns with relational views of authenticity (Nachtigall et al., 2024): authenticity emerged from students' engagement with a real technological malfunction rather than from a deliberately staged instructional context.

A second concept pertains to epistemic constraint and the constructive postponement of explanation. The design illustrates the need to refrain from authoritative narratives during the initial stages of interaction. By permitting students to observe, articulate, and hypothesize prior to the introduction of technical representations, the educator facilitated epistemic ownership and comprehension. This corresponds with studies on inquiry and problem-based learning, which highlight that premature explanations can hinder engagement and conceptual growth (Hmelo-Silver et al., 2007; Windschitl et al., 2008). The principle is not that teachers should refrain from explaining, but rather that explanations should be appropriately timed to address the epistemic needs experienced by learners. In this instance, representations gained significance as students had previously faced a situation that could not be addressed with available resources.

The third principle pertains to the meticulous management of representational transitions. Comprehending technological systems necessitates the integration of several levels of description, ranging from macroscopic characteristics to microscopic mechanisms. The design facilitated this coordination through the sequencing of representations and by preserving the simultaneous presence of the reality and the graphic. Students were consistently encouraged to transition between their visual observations on the screen and their inferences regarding the internal structure. This notion is firmly substantiated by research on multiple representations, indicating that learning is augmented when learners are assisted in translating and aligning representations rather than passively receiving them (Ainsworth, 2006; Treagust et al., 2017). The pedagogical perspective here is that representations are not impartial conduits of information but instruments that require introduction, interpretation, and integration through engagement.

The fourth principle pertains to the development of mechanical reasoning. The design focused on constructing causal chains that connect entities, activities, and outcomes rather than on the memorization of technical facts regarding DLP technology. Students were prompted to inquire about the internal mechanisms of the device that could account for the observed effect. This attitude is fundamental to physics as a field and to modern scientific explanatory models (Chi, 2005; diSessa, 2007). The notion is that technological environments can facilitate the advancement of mechanical reasoning when focus is placed on structure and process rather than on superficial function. This challenges methodologies that regard technology solely as an application of physical principles instead of as a domain for their development.

The fifth principle pertains to the effective utilization of anomalies and restrictions. Instead of rectifying students' first hypotheses, the teacher encouraged them to evaluate their concepts against the stability and characteristics of the phenomenon. The continued presence of the white dots in the projector's internal menu, for instance, served as a limitation that undermined software-based interpretations. This use of restrictions corresponds with studies on conceptual transformation, highlighting the significance of anomalies and counterevidence in stimulating the revision of ideas (Chi, 2005; Vosniadou, 2013). The design principle aims to enable the phenomenon to "push back" against explanations, thereby diminishing dependence on teacher authority and enhancing reliance on evidence.

The sixth principle entails the explicit modeling of an inquiry-oriented approach to classroom occurrences. By opting not to repair the projector and publicly framing the malfunction as a learning opportunity, the teacher exemplified a professional vision that prioritizes responsiveness over control. This is especially important in teacher education, as students' experiences as learners influence their perceptions of teaching (Grossman et al., 2009; Korthagen, 2010). The notion is that teachers' responses to unforeseen situations convey significant messages regarding the essence of teaching and learning. Viewing breakdowns as opportunities instead of threats can foster flexibility and curiosity in prospective educators.

The seventh principle pertains to the amalgamation of cognitive, emotive, and pedagogical aspects of learning. The design did not separate conceptual comprehension from participation or pedagogical contemplation. The students' curiosity, surprise, and delight were essential components of the learning process. Investigations into interest development indicate that these emotive reactions can facilitate prolonged cognitive engagement (Hidi & Renninger, 2006; Palmer, 2009). The design principle is to acknowledge emotional responses as assets instead of distractions, creating environments where affect, cognition, and pedagogy mutually enhance each other.

A principle about the utilization of commonplace classroom infrastructure as educational content has finally emerged. The projector was not introduced into the classroom as a pedagogical tool; it was already present. The design utilized an existing component of the learning environment and redesigned it pedagogically. This aligns with the emphasis on highlighting the materiality of technology and assisting learners in perceiving physics in their surrounding environment (de Vries, 2005; Hsu & Ching, 2020). The principle is both economical and pedagogical: significant learning opportunities can be generated without more equipment or resources by re-evaluating existing elements.

Collectively, these principles delineate a cohesive pedagogical position. They propose that technological failures can be systematically and effectively included into physics education, not merely as sporadic oddities but as valid foundations for investigation. The principles do not dictate specific tasks but provide guidance for observation, framing, and design. They encourage educators to adopt an alternative perspective on classroom occurrences, to regard imperfections as pedagogically beneficial, and to have confidence in students' ability to construct meaning.

From a theoretical standpoint, these concepts also enhance ongoing discussions regarding authenticity, inquiry, and the essence of scientific comprehension. They endorse relational perspectives on authenticity, model-driven methodologies for learning, and mechanical interpretations of explanation. They provide tangible guidance for educators and teacher trainers aiming to foster inquiry-based classrooms. The transferability of these principles depends on several contextual conditions, including the visibility of the malfunction, the availability of time for exploratory discussion, and classroom norms that support inquiry and collaborative reasoning. The design principles articulated herein serve as a conduit between theory and practice, anchored in a comprehensive analysis of a singular, commonplace, yet epistemically significant classroom occurrence.

IMPLICATIONS FOR TEACHER EDUCATION AND PRACTICE

Building on the outcomes identified above, the instructional design has several implications for teacher education and routine classroom practice. This study fundamentally challenges prevailing norms regarding the management of technological failures in educational environments. In most classrooms, faults are regarded as disturbances and must be mitigated to preserve lesson continuity and teacher authority. This orientation is firmly established and frequently reinforced in teacher education by emphasizing classroom management, readiness, and seamless execution. This case indicates that such an orientation may be pedagogically restrictive. By reconceptualizing breakdowns as chances for exploration, educators can create epistemic spaces that would otherwise be unattainable.

This holds particular significance for teacher education. Pre-service educators frequently encounter worry around the potential loss of classroom authority, particularly with technology. They may apprehend that failures compromise their competence or credibility. By intentionally demonstrating an inquiry-based approach to addressing malfunctions, the instructor in this study conveyed an alternative professional perspective: that teaching is not centered on impeccable execution but on astute reactivity to the material environment. It should be noted, however, that adopting such an approach requires pedagogical confidence, institutional tolerance for deviation from planned instruction, and classroom cultures that support exploratory discourse rather than immediate resolution. This corresponds with situational approaches on teacher learning, which highlight the cultivation of professional judgment via experience and reflection, rather than via the mere acquisition of skills (Korthagen, 2010). Encountering an educator who remains composed, refrains from apologies, and avoids hastily resolving issues, while instead engaging students in sense-making, can significantly shape the professional identities of pre-service teachers.

The design indicates that teacher education programs ought to more clearly consider the instructional potential of unforeseen occurrences. A significant portion of teacher preparation emphasizes lesson planning, curricular alignment, and assessment, sometimes implicitly suggesting that effective teaching equates to predictability and control. Although planning is undeniably significant, it fails to equip educators for the epistemic complexity of the unforeseen. Incorporating instances of technological failures, experimental irregularities, and unexpected occurrences into teacher education may foster curiosity and adaptability in future educators. This approach aligns with research highlighting the significance of professional vision, which encompasses the capacity to see and evaluate critical classroom occurrences (Grossman et al., 2009).

The ramifications for daily teaching practice are similarly significant. The research indicates that educators can utilize current classroom infrastructure as instructional resources. Projectors, sensors, interactive boards, and defective equipment may serve as subjects of investigation. This contests the conventional distinction between “content” and “tools,” advocating for a more cohesive perspective wherein technology is recognized as a valid domain for physics education (de Vries, 2005; Hsu & Ching, 2020). This approach is cost-effective and grounded in phenomena already present in the classroom environment.

The focus on mechanical reasoning has practical consequences for teaching methods. Physics educators frequently encounter difficulties in advancing students from mere formulaic manipulation to causal elucidation. Technological systems provide substantial contexts for such elucidation, as they manifest physical principles in tangible form. By inquiring not only into the usage of a device but also its functionality and reasons for failure, educators can foster the development of explanatory competence, which is essential for scientific literacy (Chi, 2005; diSessa, 2007). This method also corresponds with educational objectives that prioritize comprehension rather than rote memorizing.

Another significant implication pertains to the influence of affect in the learning process. The research indicates that surprise, amusement, and curiosity serve as resources rather than distractions. When students laugh incredulity at the concept of myriad little mirrors or exhibit intrigue regarding the mechanisms of a familiar apparatus, they are not disengaging; rather, they are engaging in an alternative manner. Acknowledging and appreciating these emotional responses can assist educators in establishing learning environments that are intellectually and emotionally enriching (Hidi & Renninger, 2006; Palmer, 2009). This is especially significant in physics, a discipline frequently regarded as arid or daunting.

The research indicates that accepting failure can enhance a more accurate and analytical comprehension of technology. In modern civilization, technologies are frequently depicted as seamless, efficient, and dependable. Exposing students to the vulnerabilities and constraints of actual systems can mitigate techno-optimistic fallacies and foster a more sophisticated understanding of the interplay between science, technology, and society. Critical viewpoints are widely acknowledged as essential elements of scientific and technical literacy (de Vries, 2005).

The ramifications extend to the classroom culture. Addressing breakdowns as communal issues to be comprehended rather than as personal failures to be concealed can cultivate a sense of community and collaborative exploration. Students are encouraged to collaborate, hypothesize, refine, and learn from each other. This facilitates participation forms that are essential to effective disciplinary engagement (Chinn et al., 2011; Windschitl et al., 2008).

Gradually, these methods can foster classrooms where doubt is accepted and elucidation is esteemed.

In conclusion, the study indicates that technological breakdown should be pedagogically addressed. Instead of being regarded as a source of shame or hindrance, it can be welcomed as a productive asset. In teacher education, this entails fostering dispositions of responsiveness, curiosity, and epistemic openness. In the context of classroom practice, it entails reconceptualizing the material environment as a landscape of potential phenomena. Such transformations necessitate both individual initiative and institutional backing, as educators must feel authorized to diverge from established plans and to embrace uncertainty. Nevertheless, the prospective benefits of engagement, comprehension, and authenticity are considerable.

CONCLUSION

This work has introduced and examined an educational design that reconceptualizes technological failure as an epistemic resource for physics education. This case of a malfunctioning DLP projector exhibiting persistent white dots illustrates how an unexpected classroom occurrence can be converted into a structured learning sequence that fosters observation, hypothesis formulation, modeling, mechanistic reasoning, and pedagogical reflection. The analysis reveals that technological failure, when carefully contextualized and structured, can serve as a significant epistemic resource instead of a hindrance.

The study advances research on discrepant events and inquiry-based learning by showing how unscripted technological breakdowns—rather than teacher-designed anomalies—can serve as authentic phenomena around which mechanistic explanation and epistemic reframing emerge.

This work’s primary contribution is its expression of a pedagogical approach to imperfection. In many educational practices, seamless operation is synonymous with quality, while disruption is synonymous with failure. This study contests this equation. It posits that breakdown can be educationally beneficial as it interrupts routine, exposes materiality, and necessitates elucidation. A projector’s failure reveals the underlying physics within its design. A sensor defect raises inquiries regarding measurement, calibration, and noise. Such moments are not diversions from the curriculum; they constitute the curriculum, manifested in real time.

The story underscores the significance of phenomenon-first design. The design commences with a perplexing phenomenon, permitting the conceptual framework to develop in reaction, rather than first presenting concepts and subsequently exploring their applications. This orientation is consistent with model-based and inquiry-driven methodologies in science education and fosters the advancement of mechanistic explanations. It also corresponds with relational theories of authenticity, wherein meaning emerges from interaction with genuine phenomena rather than from the surface realism of situations.

The study highlights the significance of demonstrating epistemic openness and professional responsiveness in teacher education. Pre-service teachers acquire knowledge not solely from the content delivered but also from the pedagogical methods employed. Through the observation of an educator who embraces uncertainty and perceives breakdowns as opportunities, students experience a divergent representation of teaching that prioritizes sense-making over control. Such experiences can influence professional identities and dispositions in ways that lectures on pedagogy cannot achieve alone.

The study concurrently recognizes its limitations. This study relies on a single case within a particular teacher-education context, and several boundary conditions should therefore be acknowledged. First, the design relies on an instructor willing and able to sustain inquiry without immediately resolving the malfunction. Such an approach requires pedagogical confidence and familiarity with inquiry-oriented discourse practices. In classrooms where instructors feel pressure to maintain uninterrupted instruction, technological breakdowns may be quickly repaired rather than explored.

Second, the approach presupposes an inquiry-supportive classroom culture in which students are comfortable proposing tentative ideas and engaging in collective reasoning. In more transmission-oriented environments, students may interpret the breakdown primarily as a logistical problem rather than as a phenomenon for explanation.

Third, practical constraints such as limited instructional time, curriculum pacing, and institutional expectations may limit opportunities to develop extended inquiry around spontaneous events. Teachers working in tightly structured curricula may find it difficult to temporarily suspend planned instruction.

These considerations suggest that technological breakdown can function productively as an instructional resource primarily in contexts where instructors have the flexibility to pause planned activities and where classroom norms support exploratory discussion. Future research could investigate how similar designs function across different educational environments, age groups, and technological contexts. Comparative analyses of various technological failures, alongside longitudinal investigations of their effects on pedagogical practices, would further strengthen understanding of this approach. Nevertheless, the case illustrates how technological breakdown can be productively incorporated into physics instruction when it is framed as a phenomenon for investigation. The design principles articulated here should therefore be understood as analytically derived possibilities rather than generalizable prescriptions.

This paper advocates for a reconceptualization of the classroom as a landscape of phenomena rather than merely a setting for planned activities. Technologies are not simply instruments; they are physical systems, and their failures reveal the underlying physics. By embracing these moments instead of evading them, educators can cultivate learning experiences that are authentic, engaging, and conceptually profound. In a time of growing technological integration in education, mastering the art of teaching with and through disruptions may be as crucial as learning to teach with seamlessly operating tools. Embracing imperfection, rather than concealing it, may constitute one of the most powerful yet underutilized strategies in physics education.

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