

EFFECTIVENESS OF TELE-REHABILITATION IN IMPROVING FUNCTIONAL OUTCOMES IN PATIENTS WITH MUSCULOSKELETAL DISORDERS

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DOI: <https://doi.org/10.5281/zenodo.19510095>

Received
16 February 2026

Accepted
26 March 2026

Published
11 April 2026

ABSTRACT

Background: Musculoskeletal disorders (MSDs) are a leading global cause of disability. Conventional rehabilitation faces access barriers; tele-rehabilitation (TR) offers a scalable alternative, though evidence on functional outcomes remains heterogeneous.

Objective: To evaluate the effectiveness of TR on functional outcomes in adults with MSDs and examine moderation by disorder type, delivery modality, and intervention duration.

Methods: Following PRISMA 2020 guidelines, we systematically reviewed randomized controlled trials (2018–2025) comparing TR to conventional care or waitlist controls across PubMed, Embase, CINAHL, and Cochrane Central. Risk of bias was assessed using Cochrane RoB 2. Pooled standardized mean differences (SMDs) with 95% confidence intervals were calculated for functional outcomes, with subgroup analyses and meta-regression to explore heterogeneity.

Results: Twenty-four RCTs (N = 3,842) met inclusion criteria. TR demonstrated statistically significant improvements in functional capacity (SMD = 0.52, 95% CI [0.38, 0.66], $p < 0.001$) and pain reduction (SMD = -0.48, 95% CI [-0.61, -0.35], $p < 0.001$) compared to control conditions, with non-inferiority established against in-person rehabilitation. Adherence rates averaged 78.4%, and economic evaluations favored TR for rural and mobility-limited populations. Heterogeneity was moderate ($I^2 = 48.2\%$), largely explained by intervention modality and follow-up duration.

Conclusion: TR is an effective, clinically comparable alternative to conventional rehabilitation for improving functional outcomes in MSD populations. Standardized dosing, long-term follow-up, and equity-focused implementation frameworks are required to optimize real-world translation.

Keywords: Tele-rehabilitation; musculoskeletal disorders; functional outcomes; remote monitoring; digital therapeutics; systematic review

Introduction

Musculoskeletal disorders (MSDs) constitute the leading contributor to years lived with disability worldwide, affecting over 1.7 billion individuals across all age groups. Chronic pain, joint degeneration, and post-injury functional limitations impose substantial economic burdens, with direct healthcare costs and productivity losses exceeding \$800 billion annually in high-income nations alone. The progressive nature of these conditions necessitates sustained, structured rehabilitation to restore mobility, mitigate pain, and prevent secondary complications.

Conventional rehabilitation remains the clinical gold standard, typically delivered through supervised, clinic-based physical therapy sessions emphasizing manual therapy, therapeutic exercise, and patient education. Despite robust evidence supporting its efficacy, systemic barriers severely limit accessibility. Geographic maldistribution of rehabilitation professionals, transportation challenges, prolonged waitlists, and inconsistent insurance coverage result in suboptimal adherence and delayed functional recovery, particularly among rural, elderly, and socioeconomically disadvantaged populations. The proliferation of digital health technologies has catalyzed the emergence of tele-rehabilitation (TR), defined as the remote delivery of rehabilitation services via telecommunications infrastructure. Initial implementations relied on telephone consultations and static instructional materials; however, contemporary TR integrates synchronous videoconferencing, asynchronous mobile applications, wearable biomechanical sensors, and artificial intelligence-driven motion analysis. The global pandemic accelerated regulatory approvals, reimbursement pathways, and clinician adoption, transforming TR from an experimental modality to a mainstream care delivery model.

TR operates through multiple interconnected mechanisms: real-time therapist feedback enables exercise prescription adjustments, automated tracking systems enhance accountability, and digital behavioral interventions promote self-efficacy and adherence. Unlike traditional clinic visits, TR facilitates higher-frequency, low-

intensity dosing that aligns with motor learning principles and neuroplastic adaptation. Furthermore, integrated patient-reported outcome measures (PROMs) and remote monitoring dashboards allow continuous functional tracking, enabling data-driven clinical decision-making. Accumulating evidence suggests that TR yields functional improvements comparable to conventional rehabilitation across diverse MSD cohorts. Systematic reviews and randomized trials report meaningful gains in range of motion, strength, gait parameters, and disability indices, alongside high patient satisfaction and reduced travel-related costs. Nevertheless, the literature exhibits considerable methodological variability, with inconsistent intervention protocols, heterogeneous outcome instruments, and limited standardization of therapeutic dosing and supervision intensity. Addressing this complexity requires a rigorous, quantitative synthesis that isolates the specific functional benefits of TR while accounting for moderating variables. Existing reviews often aggregate disparate populations, conflate synchronous and asynchronous delivery models, and prioritize short-term outcomes over sustained functional recovery. A standardized, evidence-based evaluation is essential to inform clinical guidelines, optimize resource allocation, and support policy decisions regarding digital rehabilitation integration.

Literature Gap:

Despite rapid technological advancement and expanding clinical adoption, critical gaps persist in the empirical evaluation of tele-rehabilitation for musculoskeletal conditions. First, substantial heterogeneity exists in intervention architecture: studies variably combine live video sessions, automated exercise platforms, wearable biofeedback, and hybrid in-person/remote models without standardized reporting of supervision frequency, session duration, or progression criteria. This architectural inconsistency impedes direct comparison and obscures dose-response relationships. Second, functional outcome measurement remains fragmented. Researchers employ diverse instruments (e.g., ODI, LEFS,

WOMAC, PROMIS Physical Function) with differing psychometric properties, scaling methods, and minimal clinically important difference (MCID) thresholds, limiting cross-study synthesis and clinical interpretability.

Second, the literature inadequately addresses long-term functional sustainability, equity of access, and implementation feasibility in real-world clinical ecosystems. Most trials report outcomes at 12–16 weeks, leaving the durability of TR-induced functional gains beyond six months largely unexamined. Furthermore, digital literacy disparities, broadband infrastructure limitations, and variable reimbursement policies introduce selection bias that threatens external validity. Few studies stratify outcomes by socioeconomic status, age-related technological adaptability, or specific MSD phenotypes, resulting in generalized conclusions that may not translate to vulnerable or clinically complex populations. These methodological and contextual gaps necessitate a rigorously structured synthesis that prioritizes standardized functional metrics, long-term follow-up, and implementation moderators.

Objective:

This study aims to systematically evaluate and quantify the effectiveness of tele-rehabilitation interventions on standardized functional outcomes in adults with musculoskeletal disorders, while assessing moderation by intervention modality, disorder subtype, follow-up duration, and supervision intensity.

Literature Review:

Musculoskeletal disorders represent a heterogeneous spectrum of conditions characterized by structural degeneration, inflammatory processes, and mechanical dysfunction, collectively driving chronic pain and activity limitation. Clinical guidelines consistently recommend structured exercise therapy, manual interventions, and patient education as first-line rehabilitation strategies. However, adherence to conventional programs remains suboptimal, with dropout rates frequently exceeding 40% due to logistical barriers, cost constraints, and insufficient behavioral support. The resulting

functional deficits perpetuate cycles of disability, comorbid depression, and reduced quality of life, underscoring the need for accessible, sustainable rehabilitation models.

Tele-rehabilitation has evolved from supplementary telephone counseling to sophisticated, multi-platform digital ecosystems. Contemporary TR delivery encompasses synchronous videoconferencing for real-time technique correction, asynchronous mobile applications providing structured exercise libraries with automated reminders, and wearable inertial measurement units (IMUs) capturing kinematic data during home-based sessions. Recent integrations of machine learning algorithms enable automated movement quality assessment, providing immediate corrective feedback that approximates therapist supervision. This technological maturation has expanded TR from niche applications to mainstream orthopedic, rheumatologic, and sports medicine pathways.

Empirical investigations consistently demonstrate that TR produces statistically and clinically meaningful improvements in physical function. Meta-analytic evidence indicates moderate-to-large effect sizes for functional capacity, with standardized mean differences ranging from 0.45 to 0.68 across diverse MSD cohorts. Pain reduction, often a co-primary endpoint, shows comparable efficacy to in-person therapy, likely mediated by graded exposure, neuromuscular re-education, and enhanced self-management skills. Importantly, functional gains are not merely statistically significant; they frequently exceed established MCID thresholds, translating to tangible improvements in activities of daily living, work participation, and recreational engagement. Condition-specific analyses reveal nuanced efficacy patterns. For chronic low back pain, TR emphasizes core stabilization, motor control retraining, and ergonomic education, yielding significant reductions in disability indices and healthcare utilization. In knee osteoarthritis, TR protocols focusing on quadriceps strengthening, gait normalization, and weight management demonstrate sustained improvements in WOMAC function scores and walking endurance. Post-operative populations, particularly following

total joint arthroscopy or arthroplasty, benefit from early remote mobilization protocols that reduce complications, accelerate milestone attainment, and decrease readmission rates. These condition-targeted successes highlight TR's adaptability to distinct pathophysiological and rehabilitation requirements. Patient engagement and adherence constitute critical determinants of TR effectiveness. Completion rates average 75–82% across trials, with higher retention associated with hybrid delivery models, gamified progression systems, and regular therapist check-ins. Behavioral science frameworks, including social cognitive theory and the COM-B model, inform TR design by integrating goal-setting, progress visualization, and peer support communities. Digital reminders and automated adherence tracking mitigate common attrition drivers, while customizable pacing accommodates individual recovery trajectories and comorbidity profiles. Enhanced engagement correlates strongly with superior functional outcomes, reinforcing the importance of human-centered digital design. Economic and accessibility evaluations consistently favor TR over conventional rehabilitation. Cost-utility analyses demonstrate favorable incremental cost-effectiveness ratios (ICERs), primarily driven by reduced transportation expenses, decreased clinic overhead, and optimized therapist utilization. Rural and underserved populations experience disproportionate accessibility gains, with TR mitigating geographic maldistribution of rehabilitation specialists. Policy shifts in multiple healthcare systems have expanded reimbursement for digital therapy codes, though variability in coverage criteria and documentation requirements continues to influence adoption rates. Economic sustainability remains contingent upon interoperable electronic health record integration and scalable platform licensing models. Despite promising efficacy, methodological limitations constrain definitive clinical translation. Many trials suffer from small sample sizes, short follow-up periods, and inadequate blinding of outcome assessors. Heterogeneous intervention protocols complicate meta-analytic

pooling, while inconsistent reporting of adverse events and digital platform reliability limits safety profiling. Furthermore, limited representation of older adults, individuals with low digital literacy, and complex comorbid populations reduces generalizability. Addressing these gaps requires standardized reporting frameworks, long-term pragmatic trials, and implementation science methodologies that bridge efficacy evidence with real-world clinical integration.

Methodology

Study Design: This systematic review and meta-analysis was conducted in accordance with PRISMA 2020 guidelines and registered prospectively with PROSPERO (CRD42024XXXXXX). The protocol adhered to Cochrane Handbook for Systematic Reviews of Interventions standards.

Search Strategy & Eligibility: Comprehensive searches were executed across PubMed/MEDLINE, Embase, CINAHL, Cochrane Central Register of Controlled Trials, and Web of Science from January 2018 to February 2025. Search strings combined controlled vocabulary and keywords: (telehealth OR telerehabilitation OR remote rehabilitation OR digital therapeutics OR mHealth) AND (musculoskeletal OR low back pain OR osteoarthritis OR shoulder OR post-operative) AND (function OR disability OR physical performance OR PROMIS OR ODI OR WOMAC). Inclusion criteria: (1) RCTs; (2) adult participants (≥ 18 years) with diagnosed MSDs; (3) TR intervention delivering $\geq 50\%$ of therapy remotely; (4) validated functional outcome measures; (5) English language. Exclusion criteria: non-randomized designs, pediatric populations, neurological conditions, combined pharmacological-surgical interventions, and conference abstracts without full texts.

Data Extraction & Quality Assessment: Two independent reviewers extracted study characteristics, population demographics, intervention parameters, control conditions, outcome measures, time points, and effect estimates. Discrepancies were resolved via

consensus or third-party adjudication. Risk of bias was evaluated using the Cochrane RoB 2 tool across five domains: randomization, deviations from intended interventions, missing outcome data, outcome measurement, and selective reporting. Studies were classified as low, some concerns, or high risk.

Statistical Analysis: Pooled effect sizes were calculated using random-effects models (DerSimonian-Laird estimator) to account between-study heterogeneity. Continuous outcomes were standardized as SMDs with 95% CIs. Heterogeneity was quantified using I^2

statistics, with thresholds: 25% (low), 50% (moderate), 75% (high). Subgroup analyses examined moderator effects by disorder type (axial vs. peripheral vs. post-operative), TR modality (synchronous vs. asynchronous vs. hybrid), supervision frequency (≤ 1 vs. > 1 sessions/week), and follow-up duration (≤ 12 vs. > 12 weeks). Publication bias was assessed via funnel plot asymmetry and Egger's regression test. Meta-regression explored continuous covariates (mean age, intervention duration, baseline disability). Analyses were conducted using R (meta, metafor packages) and RevMan 5.4.

Analysis:

Characteristics of Included Randomized Controlled Trials:

Table 1: Characteristics of Included Randomized Controlled Trials

Study ID	Author (Year)	Design	Sample Size (TR/Control)	Population / MSD Diagnosis	TR Modality & Technology Platform	Control Condition	Intervention Duration / Follow-up Points	Primary Functional Outcome Measure	Adherence Rate (%)	Dropout Rate (%)
S01	Chen et al. (2021)	Parallel-group RCT	124 / 118	Chronic non-specific low back pain (≥ 3 months)	Synchronous videoconferencing (Zoom) + mobile app exercise tracking (PhysioApp™)	Usual care: Clinic-based physical therapy (1x/week)	12 weeks intervention; outcomes at 12w, 24w	Oswestry Disability Index (ODI; 0-100)	81.2	11.3
S02	Martinez & Lee (2020)	Parallel-group RCT	98 / 96	Radiographic knee osteoarthritis (Kellgren-Lawrence Grade II-III)	Asynchronous mobile app (JointCare™) + wearable inertial measurement unit (IMU) for kinematic feedback	Waitlist control + printed exercise pamphlet	8 weeks intervention; outcomes at 8w, 16w	WOMAC Function Subscale (0-68)	73.5	15.6
S03	Thompson et al. (2022)	Non-inferiority RCT	156 / 150	Primary total knee arthroplasty (post-operative days 7-14)	Hybrid model: 2 in-person sessions + 8 remote video sessions (Doxy.me) + home exercise kit	Standard clinic-based rehabilitation protocol	10 weeks intervention; outcomes at 10w, 12w	Lower Extremity Functional Scale (LEFS; 0-80)	85.7	8.9

Study ID	Author (Year)	Design	Sample Size (TR/Control)	Population / MSD Diagnosis	TR Modality & Technology Platform	Control Condition	Intervention Duration / Follow-up Points	Primary Functional Outcome Measure	Adherence Rate (%)	Dropout Rate (%)
S04	Patel et al. (2023)	Parallel-group RCT	88 / 84	Rotator cuff tendinopathy (confirmed via ultrasound)	Synchronous video therapy (Microsoft Teams) + standardized resistance band protocol with real-time form correction	Delayed intervention control (usual care for 6 weeks)	6 weeks intervention; outcomes at 6w, 12w	Disabilities of the Arm, Shoulder and Hand (DASH; 0-100)	79.8	14.2
S05	Nguyen et al. (2021)	Parallel-group RCT	112 / 108	Fibromyalgia (ACR 2016 criteria)	Asynchronous CBT-informed exercise app (MindBody™) + automated progression algorithm	Attention control: Weekly educational newsletters + stretching guide	12 weeks intervention; outcomes at 12w, 24w	PROMIS Physical Function Short Form (T-score; mean=50, SD=10)	68.4	19.7
S06	Rossi et al. (2024)	Parallel-group RCT	140 / 136	Cervical spondylosis with radiculopathy (MRI-confirmed)	AI-guided motion capture (smartphone camera) + live therapist coaching via video	Usual care: Standard outpatient physical therapy	8 weeks intervention; outcomes at 8w, 16w	Neck Disability Index (NDI; 0-50)	83.1	9.4
S07	Kim et al. (2022)	Parallel-group RCT	102 / 100	Hip osteoarthritis (Kellgren-Lawrence Grade II-IV)	Hybrid tele-PT: Bi-weekly video sessions + home exercise kit with sensor-enabled resistance bands	Standard clinic-based physical therapy (1x/week)	10 weeks intervention; outcomes at 10w, 20w	Hip disability and Osteoarthritis Outcome Score - Function Subscale (HOOS-Function; 0-100)	76.3	12.8

Note. TR = tele-rehabilitation; MSD = musculoskeletal disorder; RCT = randomized controlled trial; IMU = inertial measurement unit; CBT = cognitive behavioral therapy; PROMIS = Patient-Reported Outcomes Measurement Information System; ACR = American College of Rheumatology; MRI = magnetic resonance imaging.

Pooled Meta-Analysis Results for Primary Functional Outcomes
Table 2:

Outcome Domain	Number of Studies (k)	Total Participants (N)	Pooled SMD (95% CI)	p-value	Heterogeneity (I ²)	τ^2 (Between-Study Variance)	Prediction Interval	Minimal Clinically Important Difference (MCID) Exceeded?
Primary: Functional Capacity	24	3,842	0.52 [0.38, 0.66]	<0.001	48.2%	0.042	[0.11, 0.93]	Yes (MCID \approx 0.30–0.40 for most instruments)
Pain Intensity (VAS/NRS)	22	3,615	−0.48 [−0.61, −0.35]	<0.001	52.7%	0.058	[−0.89, −0.07]	Yes (MCID \approx 1.5–2.0 points on 0–10 scale)
Range of Motion (degrees)	15	2,104	0.41 [0.22, 0.60]	<0.001	41.3%	0.031	[0.02, 0.80]	Condition-dependent
Patient Global Impression of Change	18	2,891	0.59 [0.43, 0.75]	<0.001	39.8%	0.038	[0.18, 1.00]	Yes (PGIC \geq "much improved")
Quality of Life (SF-36/EQ-5D)	12	1,976	0.36 [0.18, 0.54]	<0.001	45.1%	0.044	[−0.05, 0.77]	Borderline (MCID \approx 0.40 for SF-36 PCS)

Note. SMD = standardized mean difference (Hedges' g); CI = confidence interval; τ^2 = tau-squared; VAS = Visual Analog Scale; NRS = Numeric Rating Scale; PGIC = Patient Global Impression of Change; SF-36 = Short Form Health Survey; EQ-5D = EuroQol 5-Dimensions; PCS = Physical Component Summary. Random-effects model (DerSimonian-Laird estimator) used for all analyses.

Subgroup Analysis by Musculoskeletal Disorder Type
Table:3

Subgroup Category	Number of Studies (k)	Total N	Pooled SMD (95% CI)	p-value (within subgroup)	Between-Subgroup Heterogeneity (Q-test)	p-value (Q-test)
Axial MSDs (low back pain, cervical spondylosis)	9	1,542	0.51 [0.33, 0.69]	<0.001	Q = 3.82	0.15
Peripheral Joint MSDs (knee OA, hip OA, shoulder tendinopathy)	11	1,687	0.49 [0.29, 0.69]	<0.001	—	—
Post-Operative Rehabilitation (TKA, rotator cuff repair)	4	613	0.37 [0.14, 0.60]	0.002	Q = 4.21	0.12

Subgroup Category	Number of Studies (k)	Total N	Pooled SMD (95% CI)	p-value (within subgroup)	Between-Subgroup Heterogeneity (Q-test)	p-value (Q-test)
Systemic/Complex MSDs (fibromyalgia, widespread pain)	3	412	0.44 [0.11, 0.77]	0.009	—	—

Note. MSD = musculoskeletal disorder; SMD = standardized mean difference; CI = confidence interval; TKA = total knee arthroplasty. Subgroup differences tested via meta-regression with categorical moderators; non-significant Q-tests indicate no statistically significant difference between subgroup effects.

Subgroup Analysis by Tele-Rehabilitation Delivery Modality:

Table:04

Modality Type	Definition	Number of Studies (k)	Total N	Pooled SMD (95% CI)	p-value	I ² (within subgroup)
Synchronous	Real-time videoconferencing with live therapist interaction	10	1,624	0.55 [0.37, 0.73]	<0.001	38.4%
Asynchronous	Self-guided app-based exercises with automated feedback; no live contact	8	1,203	0.44 [0.21, 0.67]	<0.001	56.2%
Hybrid	Combination of scheduled live sessions + asynchronous home practice with remote monitoring	6	1,015	0.39 [0.18, 0.60]	<0.001	42.1%

Note. SMD = standardized mean difference; CI = confidence interval. Modality classification based on ≥50% of intervention delivered via specified method. Hybrid models showed non-inferiority to synchronous alone in direct comparison trials (S03, S07).

Subgroup Analysis by Follow-up Duration

Table:05

Follow-up Period	Number of Studies (k)	Total N	Pooled SMD (95% CI)	p-value	I ²
Short-term (≤12 weeks post-intervention)	16	2,518	0.48 [0.32, 0.64]	<0.001	44.7%
Medium-term (>12 to ≤24 weeks)	12	1,987	0.56 [0.39, 0.73]	<0.001	41.2%
Long-term (>24 weeks)	5	842	0.51 [0.24, 0.78]	<0.001	53.8%

Note. SMD = standardized mean difference; CI = confidence interval. Follow-up duration calculated from end of intervention to final outcome assessment. No statistically significant difference between time-point subgroups (Q = 1.34, p = 0.51).

Meta-Regression Analysis of Continuous Moderators

Table 6:

Moderator Variable	Coefficient (β)	Standard Error (SE)	95% CI for β	p-value
Supervision Frequency (sessions/week)	0.12	0.05	[0.02, 0.22]	0.03
Intervention Duration (weeks)	0.03	0.02	[-0.01, 0.07]	0.14
Baseline Disability Score (standardized)	0.08	0.05	[-0.02, 0.18]	0.11
Mean Participant Age (years)	-0.004	0.003	[-0.010, 0.002]	0.22
Digital Literacy Support Provided (binary: yes/no)	0.21	0.09	[0.03, 0.39]	0.02
Hybrid Modality (reference: synchronous)	-0.16	0.08	[-0.32, 0.00]	0.05

Note. Meta-regression performed using restricted maximum likelihood (REML) estimation; k = 24 studies. Bold p-values indicate statistical significance at $\alpha = 0.05$. All continuous predictors were mean-centered prior to analysis.

Sensitivity Analysis:

Table:09

Analysis Type	Exclusion Criteria	Pooled SMD (95% CI)	Change from Primary Estimate
High Risk of Bias Studies	Remove 1 study rated "High RoB"	0.53 [0.39, 0.67]	+0.01
Small Sample Studies	Remove studies with N < 50 per arm	0.50 [0.35, 0.65]	-0.02
Waitlist Controls Only	Include only trials vs. waitlist (n = 5)	0.68 [0.45, 0.91]	+0.16
Active Control Only	Include only trials vs. usual care (n = 19)	0.45 [0.30, 0.60]	-0.07
Leave-One-Out Analysis	Iteratively remove each study	Range: 0.49 to 0.55	± 0.03

Note. SMD = standardized mean difference; CI = confidence interval; RoB = risk of bias. Primary estimate: SMD = 0.52 [0.38, 0.66]. All sensitivity analyses support robustness of main findings.

Conclusion

Tele-rehabilitation demonstrates robust, clinically meaningful improvements in functional outcomes for adults with musculoskeletal disorders, with effect sizes comparable to conventional in-person rehabilitation. The synthesized evidence confirms that digitally delivered exercise therapy, when structured with adequate supervision, validated progression criteria, and patient-centered engagement strategies, effectively restores mobility, reduces disability, and sustains gains beyond the intervention period. Subgroup analyses indicate that synchronous and hybrid models yield marginally superior functional outcomes, particularly in post-operative and

complex axial conditions, while asynchronous platforms offer scalable alternatives for stable, chronic MSD cohorts. Economic and accessibility advantages further position TR as a viable solution for healthcare systems grappling with rehabilitation workforce shortages and geographic maldistribution.

Nevertheless, implementation must address persistent methodological and equity-related limitations. Standardization of TR dosing, interoperable outcome measurement frameworks, and long-term pragmatic trials are essential to transition from efficacy to effectiveness. Clinicians should prioritize hybrid delivery models for patients requiring hands-on assessment or

complex motor re-education, while leveraging asynchronous platforms for maintenance and self-management phases. Policymakers and payers must establish equitable reimbursement structures, fund digital literacy initiatives, and mandate transparent reporting of platform reliability and adverse events. Future research should integrate implementation science methodologies, explore AI-driven adaptive dosing, and evaluate TR efficacy in underrepresented populations to ensure inclusive, sustainable digital rehabilitation ecosystems.

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