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Transition From Tinkercad Virtual Laboratory to Physical Internet of Things Practicum: A Single-Case Study

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Abstract
Internet of Things (IoT) instruction in secondary schools requires hands-on practice, and virtual laboratories such as Tinkercad Circuits are widely used to prepare students beforehand. However, readiness formed in simulation may not carry over to physical devices, and prior studies have mostly assessed the effectiveness of virtual laboratories rather than how the shift to physical devices is managed. This study describes how Tinkercad-oriented Informatics learning is managed, the role of simulation before practicum, and its integration with physical IoT practicum, including the transition process. A descriptive single-case study was conducted at SMA Al Islam 1 Surakarta in Grade XII Moving Class 4 and 5 (35 students). Data came from interviews with five informants, observation of two classroom sessions, and document review, analyzed thematically with triangulation and follow-up confirmation. Tinkercad served as a pre-practicum stage but was not formalized in the teaching module, and the teacher judged readiness without written criteria. The transition unfolded in four stages: preparation, transition, adjustment, and verification. Students had to adapt to physical conditions such as reversed LED legs and loose wires, while circuit logic and code remained usable. Written readiness criteria and explicit adjustment time are recommended; competence gains were not measured.

Keywords: internet of things practicum; learning management; tinkercad; virtual laboratory; virtual-to-physical transition

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INTRODUCTION

Informatics in the Merdeka Curriculum places computational thinking and digital literacy at the core of student competence (Sugiarti et al., 2023). Technical competence is not built through conceptual understanding alone, because it requires direct experience in testing and repairing one's work, and practicum bridges concepts and technical skills (Wahyudiati, 2016). The need is evident in Internet of Things (IoT) learning, whose competencies span four layers: *sensing*, *networking*, *services*, and *interface* (Abichandani et al., 2022). Providing such practicum in general secondary schools depends on hardware, networks, and teacher readiness, and technology-based instruction in general depends on teachers' technological competence and leadership support (Akram et al., 2022). Limited laboratory facilities in vocational high schools in Pekanbaru, for example, led to the proposal of a virtual laboratory concept (Herlandy et al., 2020).

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The problem at SMA Al Islam 1 Surakarta is not merely a lack of facilities. The school owns IoT practicum devices and Tinkercad access, and its laboratory became available only in November 2026, so practice in this study took place in the classroom. A preliminary study (initial observation and informal interviews with the Informatics teacher) showed that Tinkercad was used before the physical practicum but was not included in planning documents; that readiness criteria and the transition procedure were unwritten; and that technical constraints arose around time, network access, accounts, and shared devices.

Virtual laboratories are interactive computer-based simulations that allow experiments without risk or physical resource limits (Tatli & Ayas, 2013), and Tinkercad Circuits is widely used to design and test circuits and Arduino microcontrollers without physical components (Abburi et al., 2021). Yet virtual laboratories are designed to support, not replace, physical practicum (Li & Liang, 2024), which raises a conceptual question: readiness formed in simulation is not necessarily readiness for physical devices with real conditions and limits. In a distance embedded-systems course, physical Arduino kits felt more concrete and motivating but produced contact failures that hindered troubleshooting, whereas the simulator allowed connection testing without risk of damage (Myllymäki & Hakala, 2022). Two lenses are used to read the phenomenon as a managed process. The learning management (planning, organizing, actuating, and controlling; POAC) view treats learning as a cycle of setting goals, allocating resources, implementing, and assessing (Nurhikmah, 2024); here, these are mapped to planning, implementation (organizing and actuating), and evaluation (controlling). Diffusion of innovations theory (Rogers, 2003) explains, through five attributes (relative advantage, compatibility, complexity, trialability, and observability), how teachers and students accept and adapt to an innovation (Çakıroğlu et al., 2022), and is used as a lens for supporting and inhibiting factors. Both are initial analytical frameworks, not hypotheses.

Previous research has not answered this question. Tinkercad studies focus on usability and learning experience (Erdogan et al., 2023; Tüysüz et al., 2024), and large-scale reviews of virtual laboratories focus on aggregate efficacy, which varies by design and context (Fadda et al., 2022), relates to motivation (Li & Liang, 2024), and has a moderate effect on outcomes (Santos & Prudente, 2022). Herlandy et al. (2020) likewise examined a virtual laboratory through learning outcomes, leaving aspects such as teachers' ability to use it unexamined. IoT education reviews map curriculum, pedagogy, and assessment (Abichandani et al., 2022), and learning-management studies remain general (Nurhikmah, 2024). Negahban (2024) discusses the shift from physical experiments to simulation in engineering education, and the closest studies compare simulators with physical devices in higher education (Muñoz-Ubando, 2025; Myllymäki & Hakala, 2022), focusing on student experience and outcomes rather than on managing the transition in secondary schools. In the authors' search, no study examined that management.

Accordingly, this study examines how learning progresses from simulation to physical devices, how discrepancies between simulated outcomes and actual device performance are addressed, and how schools organize this transition when both physical equipment and Tinkercad access are already available. This investigation is warranted because existing research has predominantly focused on the effectiveness and usability of virtual laboratories, whereas the managerial dimensions of integrating simulation-based learning with physical practicum remain insufficiently documented. Understanding these dimensions is essential to help schools determine the time allocation, implementation criteria, and institutional support required to facilitate an effective transition. The study offers three contributions: a theoretical contribution by applying the POAC framework and diffusion of innovations theory to the integration of virtual and physical learning environments; a methodological contribution through an in-depth single-case study supported by multiple data sources; and a practical contribution by providing evidence-based guidance for school-level implementation.

This descriptive single-case study at SMA Al Islam 1 Surakarta aims to (1) describe the management (planning, implementation, evaluation) of Tinkercad-oriented Informatics learning in IoT practicum; (2) describe the role of Tinkercad simulation at the pre-practicum stage; and (3) describe its integration with physical IoT practicum, including the transition process. Its novelty lies in focusing on managing the transition rather than media effectiveness, in the context of a private general secondary school managing its own resources, and in a four-stage transition pattern (preparation, transition, adjustment, and verification) formulated inductively from case data and tested against observation, presented as a case finding, not a new theory. It differs from earlier work in theory (managerial and adoption lenses rather than efficacy), methodology (triangulated case evidence rather than outcome measures), and data (field observation of a real class).

METHOD

This qualitative, descriptive single-case study (Yin, 2018) was conducted at SMA Al Islam 1 Surakarta, a private senior high school purposively selected because it had already used Tinkercad before the IoT practicum and had IoT devices and Tinkercad access. The case was Tinkercad-oriented Informatics learning management in the IoT practicum, and the embedded unit was one class, Grade XII Moving Class 4 and 5 (35 students), observed in Odd Semester 2026/2027. Physical practice took place in the classroom because the laboratory became available only in November 2026. The researchers selected five informants based on their direct involvement: the principal (KS), the vice principal for curriculum (WK), the Informatics teacher (GR), and two students (S1, higher-achieving, and S2, low-to-moderate-achieving, according to a diagnostic test at the start of the semester). All 35 students were observation subjects.

Data came from semi-structured interviews, non-participant observation, and document review. Interviews (10, 19, and 20 October 2026; about 30 minutes each, face to face, recorded, and transcribed) followed guides on planning, implementation, evaluation, the transition, and supporting and inhibiting factors, with pattern-deepening questions (PD) to confirm patterns across informants. Two observation sessions (6 and 20 October 2026), each of three lesson periods (3 × 40 minutes), used a 31-indicator sheet arranged by preparation, transition, adjustment, and verification: Session 1 was a Tinkercad simulation of a blinking LED with Arduino, resistor, and *breadboard*, and Session 2 added a *buzzer* and frequency before integration with physical devices. We observed Group 3 in detail as the focus group (not a focus group discussion), with Groups 5 and 6 as comparisons. Documents reviewed (D) were the teaching module, learning outcomes (CP), schedule, and assessment rubric. On 23 October 2026, we asked informants follow-up questions on seven issues that differed between interviews and observations (KU-1 to KU-7); are report these answers as informant confirmation, not observational findings. We coded observation items are O-S1 and O-S2, screenshots are coded S, and photographs are coded F. Quotations are first-person statements translated from Indonesian by the authors; other answers are paraphrased.

We analyzed the data using hybrid deductive–inductive thematic analysis (Braun & Clarke, 2006) within case description and pattern matching. We extended an initial codebook (planning, implementation, evaluation, role of simulation, integration, and the five attributes of diffusion of innovations) with inductive codes, then grouped codes into themes aligned with the objectives, with supporting and inhibiting factors as cross-cutting themes. The four-stage transition pattern was formulated inductively from the integration themes and tested against observation data; a pattern was reported only if supported by at least two sources or techniques. The study maintained trustworthiness through source and technique triangulation, member checking, peer debriefing, and an audit trail (Nowell et al., 2017). The institutional ethics committee approved the study (No. 1252/FKIP/A4.1/X/2026), with school permission,

informed consent, and, for minors, parental or guardian consent and student assent; participants are reported by role codes.

RESULTS AND DISCUSSION

Results

In planning, the teacher designed content from the CP and teaching module, considering schedule, device availability, and student readiness (GR-02, WK-01). Tinkercad was practice before physical devices but remained a habit, not a stage in the written plan (GR-03), and no written document on the transition procedure or readiness criteria existed (WK-05). The module lists Tinkercad as a learning medium only, although the vice principal first described it as a separate stage (WK-01; PD-1.1, KU-1). In implementation, the school provides facilities and policy while the teacher decides class flow (KS-03), and coordination is informal, mainly about schedule and room use (WK-02, PD-5.1). Plans changed because of slow networks, account problems, or lack of time (GR-09). Observation showed similar conditions: in Session 1, three students forgot passwords and two laptops failed to load Tinkercad (O-S1-03, O-S1-11), and in Session 2, devices were used one set per group (O-S2-13). In evaluation, the principal monitored through reports and class supervision (KS-04). An integrated rubric covers simulation and physical practice, with physical practice weighted more and professional judgment retained for cases such as broken equipment (GR-08, WK-04, PD-4.1). In Session 2 the teacher filled in a three-item rubric (circuit, code, result) (O-S2-29, D-1), confirmed as this rubric with the physical-device item weighted more (KU-5), although the weighting was not observed.

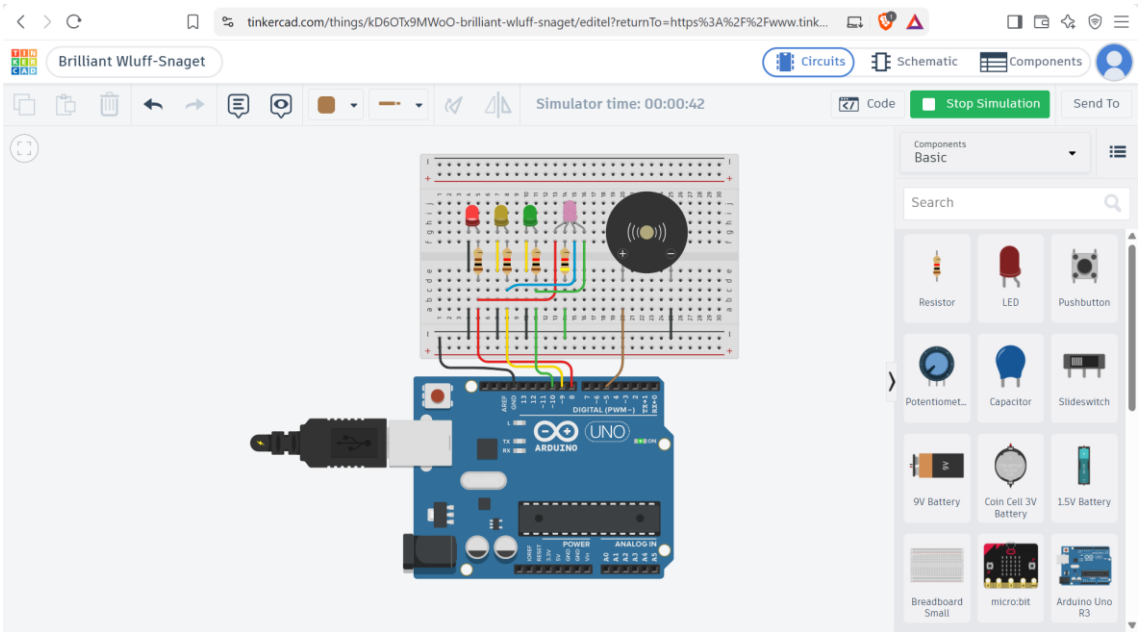


Figure 1. Simulation view of the circuit in tinkercad circuits

The teacher gave three reasons for using Tinkercad first: wiring mistakes do not damage components, experiments can be repeated, and students dare to try more (GR-03). The vice principal found it suitable for single-board-controller material (WK-07), and the principal saw simulation and devices as complementary, not a replacement (KS-06). S1 said, “Trying Tinkercad first helped me a lot because I became familiar with the component parts before using the real device” (S1-03), whereas S2 described the help as limited: “So, even though I had tried Tinkercad, I still needed to see examples and ask” (S2-03). In Session 1, Group 3 wired pin 13 through the resistor to the LED and GND (07.55), copied the sample blinking

code and changed the *delay* value (08.05), and corrected one wrong-pin wire (08.12). Table 1 summarises perceived ease and difficulty, are Figure 1 shows an example simulation.

Table 1. Ease and difficulty in tinkercad

Aspect	Interview	Observation
Selecting and placing components	Easy (GR-05, S1-04); "fairly easy" (S2-04)	Observed (O-S1-06)
Writing code	Difficult (GR-05, S1-04, S2-04); S2 used examples (S2-02)	Code copied, *delay* values changed (O-S1-07)
Connecting pins	Difficult (GR-05)	Pin errors occurred and were corrected (O-S1-09)
Understanding error messages	Difficult (GR-05)	Not recorded
Access (accounts, network)	Initial obstacle (GR-09, GR-10)	Observed (O-S1-03, O-S1-11)

The data support a four-stage transition pattern: preparation, transition, adjustment, and verification (Figure 2), each tied to interview and observation codes. The pattern derives from one class in two sessions; data support is strongest for adjustment (detailed only for Group 3) and thinnest for verification, where rubric weighting was not observed, and only some groups were recorded in detail.

In the *preparation* stage, students received concept explanations and then practised in Tinkercad (GR-01, S1-01, S2-01). In Session 1, the teacher outlined the flow: a blinking LED in Tinkercad that day; in the next meeting, a buzzer and frequency in Tinkercad, followed by practice with real devices (O-S1-01); and a display of the components and their functions (O-S1-02).

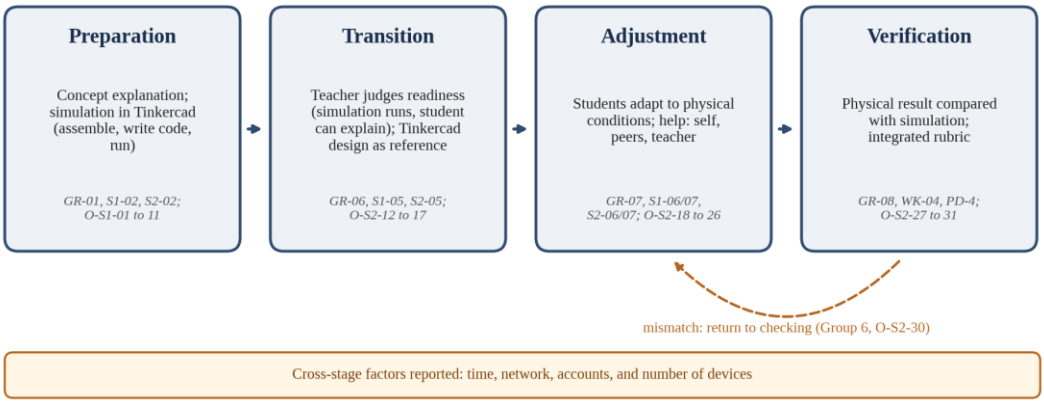


Figure 2. Four-stage transition pattern from Tinkercad simulation to physical devices in the case studied (derived from interviews and observation)

In the *transition* stage, the teacher said students are considered ready when their simulation runs and they can explain the circuit, judged more by teacher observation than by written criteria (GR-06, PD-2.1). S1 said, "I feel ready to use the real device when my simulation works as intended and I can explain how my circuit works" (S1-05), and S2 said, "I feel ready if the circuit already runs in Tinkercad, although sometimes I do not quite understand why it lights up" (S2-05). In Session 2 the teacher allowed groups whose simulation already ran to take a device, an unwritten oral criterion (O-S2-12); in the confirmation, the teacher said the running simulation was checked with brief questions, such as why the LED lights up and the function of pin 13 (KU-2), which observation did not record. Group 3 assembled while

opening the Tinkercad design (O-S2-15, O-S2-16), whereas Group 5 assembled without it and made one wrong connection (O-S2-17). Informants said students who had not finished the simulation had sometimes still been given devices when time was short (GR-06-F5, S1-05-F5, S2-05-F5), but this was not observed and did not occur on 6 and 20 October (KU-2).

In the *adjustment* stage, the teacher and students said circuit logic and program remain the same on physical devices, but physical conditions differ: loose wires, wrong pins, reversed component legs, and broken components (GR-07, S1-06). S1 said, "The way of thinking I used in Tinkercad can still be used on the real device" (S1-06), while S2 said, "When using the real device, I was more confused because the wires had to be connected directly. I was afraid of making mistakes" (S2-06). In Session 2, Group 3's LED did not light, and the *buzzer* did not sound because the LED legs were reversed and one wire was loose (08.35). Student K3-A said, "It ran in Tinkercad earlier, so why not here?" (08.38). The students replugged wires (08.36), asked the neighboring group about LED polarity (08.39), flipped the LED (08.40), and changed a pin number in the code, while the *tone* frequency stayed the same as in the simulation (08.41). They then called the teacher (08.42), who hinted without fixing it: "Try checking the LED leg, which one goes into which pin?" (08.43). The circuit worked after 14 minutes (08.31–08.45), as shown in Figure 3. This tiered help (alone, peers, then teacher) matches teacher and student statements (GR-05, S1-07, S2-07). S1 compared the real circuit with the simulation to find differences, whereas S2 sometimes did not know which part was wrong (S1-07, S2-07); as each is one student, this is not an ability-group pattern. Students also reported that programs are uploaded through Arduino IDE on physical devices, while Tinkercad needs only *Start Simulation* (KU-3), which was not observed. The laboratory-manager role in GR-07-F4 applies only to the laboratory, not to these classroom sessions (KU-6).

In the *verification* stage, students compared the LED blinking rhythm and *buzzer* tone on the physical device with the simulation (08.46); K3-B said, "It's the same as in the simulation, but the wires need to be tidied first." The teacher checked orally (08.50) and filled in the rubric (08.52). Group 3 worked fully and Group 5 partly; informants confirmed that all groups used devices and that Group 5 finished partly because one LED was dead (KU-7), a cause observation did not record. In Group 6 the LED rhythm did not match, and students returned to check the *delay* and *buzzer* frequency values (08.55), so verification can send students back to adjustment.



Figure 3. Group 3's physical circuit before (left) and after (right) adjustment (source: research documentation)

Supporting factors included existing IoT facilities (GR-10), a low-risk, repeatable simulation that could be monitored through accounts (GR-12, WK-07), and support from the teacher, peers, and group work (S1-08, S2-08). Inhibiting factors included limited lesson time (WK-03, GR-10), network and account issues (GR-09, GR-10, O-S1-03), an insufficient number of devices for students (GR-10, S1-08), and teacher competence and equipment maintenance (KS-07). Physical practice is the most likely to be cut short, while simulation also takes time because of accounts and networks (PD-3.1), so experience can differ across groups (PD-3.4).

Discussion

This study examined how learning moves from simulation to physical devices in one class, not Tinkercad effectiveness. The shift is not automatic: teachers and schools run and decide each stage, mostly informally. Students adjust to physical conditions while circuit logic and code transfer, and time, network, accounts, and device numbers constrain practice. The four stages are a case-based conceptual framework, not a tested theory; they are not linear (in Group 6, a mismatch returned students from verification to checking), and data support is strongest for adjustment and thinnest for verification.

Read through POAC (Nurhikmah, 2024), the transition appears as a managerial decision: in planning, Tinkercad is not an official stage and readiness criteria are unwritten; in implementation, plans are adjusted to network, account, schedule, and equipment constraints; in evaluation, an integrated rubric exists, but its application depends on teacher judgment. This illustrates, rather than extends, POAC, which treats learning as a cycle of goal setting, resource allocation, implementation, and assessment; the case shows where that cycle remained informal. Through the attributes in Rogers (2003), simulation was described as safe, repeatable, and free (relative advantage; KS-01, GR-03), suitable for single-board-controller material but still only a medium in the module (compatibility; WK-07), code and pins as difficult (complexity), and retryable (trialability; GR-12, S1-08); evidence on observability is thinnest. This reading is consistent with adoption studies in education (Çakıroğlu et al., 2022) but does not prove adoption. That constraints and readiness judgments rested on the teacher also fit the view that technology-based instruction depends on teachers' technological competence and leadership support (Akram et al., 2022). Finally, the adjustment stage is where students gain direct experience testing and repairing their own work, through which the practicum is said to bridge concepts and technical skills (Wahyudiati, 2016).

The findings align with reviews that position virtual laboratories as supporting media (Fadda et al., 2022; Li & Liang, 2024; Santos & Prudente, 2022) and with the principal's view that simulation and devices are complementary (KS-06). Those reviews address aggregate efficacy or motivation, whereas this study adds a field process: readiness from simulation did not automatically transfer to physical devices, as students faced reversed LED legs, loose wires, and a different upload step, while the logic and code remained usable. This echoes the contact failures reported for physical kits (Myllymäki & Hakala, 2022). De Jong et al. (2013) recommend combining physical and virtual laboratories, and this study shows how a school runs that combination: a teacher-managed sequence with unwritten criteria. Herlandy et al. (2020) concluded that an augmented-reality virtual laboratory raised vocational learning outcomes where laboratory facilities were limited, but they measured only outcomes; this study complements that by describing how teachers and the school manage virtual laboratory use. Neither the school nor this study measures competence transfer.

Several divergences revealed what a single source would hide. The formal status of Tinkercad first differed between statements (WK-01) and was clarified against the module (KU-1). Coordination was described both as reporting and supervision (KS-04) and as informal (WK-02, PD-5.1), suggesting that what is monitored is not necessarily what is planned. Shortened or turn-taking physical practice can make experience differ across groups (PD-3.4), so opportunities to learn during adjustment may be uneven; in terms of Rogers (2003), the trialability that simulation offers may not extend equally to physical practice.

Within the limits of the data, there are three contributions. First, from validation to mechanism: earlier studies mainly assess effectiveness and usability, whereas this study explains how the shift from simulation to physical devices is carried out in one case. Second, adjustment as a distinguishing stage: simulation results are a reference that still has to be adapted to physical conditions, with help from the teacher and peers. Third, a framework to test at other schools, with different materials and contexts, including measuring transfer.

These implications derive from one case and need testing. Write down the simulation stage and readiness criteria (WK-05, KS-07, WK-08). Allocate explicit time for adjustments, because limited time is the main obstacle (GR-13, WK-03). Prepare accounts and networks before activities (GR-11), communicate rubric weights to students, and provide examples and assistance to students who need them (S2-08).

The study used one school, one class, and two sessions, with adjustment and verification detailed for the focus group. The material was limited to a blinking LED and *buzzer* (so the framework does not yet cover the full range of IoT competencies, from sensing to interface); practice took place in the classroom; competence and transfer were not measured; and student perspectives came from two students. Readiness questioning, rubric weights, and the Arduino IDE upload were not observed and rest partly on informant confirmation (KU-2, KU-3, KU-5). Future studies could test the framework at several schools with broader IoT material and systematically measure transfer.

CONCLUSION

This single-case study at SMA Al Islam 1 Surakarta (Grade XII Moving Class 4 and 5, 35 students) addressed three objectives. First, Tinkercad-oriented Informatics learning is managed adaptively: Tinkercad serves as a pre-practicum stage through the teacher's habit and is not a separate stage in the module; coordination is informal; implementation adapts to network, account, time, and schedule constraints; and an integrated rubric exists but depends on teacher judgment. Second, simulation is safe, repeatable practice that familiarises students with components, pins, and program logic, although writing code and connecting pins are difficult. Third, integration with physical practicum follows four stages formulated from case data: preparation, transition, adjustment, and verification. Readiness is judged from a running simulation and the ability to explain the circuit, without written criteria; on physical devices, logic and code carry over, but students adjust to real conditions with tiered help before results are compared with the simulation and rubric. The contribution is an empirical picture of how the shift is managed in one case and a four-stage framework to be tested, not a tested theory. Schools can document the simulation stage and readiness criteria, allocate explicit adjustment time, prepare accounts and networks, and communicate rubric weights. The framework should be tested across schools, with transfer measured.

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