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Bridging the divide: The perceived efficacy of datalogging in fostering higher-order thinking and conceptual understanding in science practical's

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Abstract

Practical work has long been positioned as central to school science, yet its effectiveness in promoting genuine conceptual understanding and higher-order thinking remains contested. This study investigates whether datalogging (probeware) can help bridge the persistent gap between "hands-on" activity and "minds-on" learning in science practicals. Drawing on Millar and two-domain model of practical work, the research explores science teachers' perceptions of datalogging as a mediator between the domain of objects and observables and the domain of scientific ideas. Adopting a post-positivist stance and a large-scale cross-sectional survey design, an online questionnaire was distributed to 62,340 named science teachers across the UK, USA, Australia, Ireland, and New Zealand, yielding 2,126 valid responses. Exploratory factor analysis of 21 Likert-scale items identified two robust latent constructs: Datalogging as a Facilitator of inquiry, higher-order thinking, and conceptual understanding; and Teacher Apprehension, capturing concerns about reliability, setup time, and classroom management. Multiple regression analyses showed that positive perceptions of datalogging were strongly associated with greater proportions of hands-on practical time and specific subject specialisms, indicating that the pedagogical context strongly conditions the perceived efficacy of the technology. Teachers reported that datalogging particularly enhances students' ability to interpret graphs, link observations to theory, and engage in open-ended, investigative work. At the same time, apprehension about technical complexity emerged as a non-trivial barrier to adoption. The study concludes that datalogging is perceived not as a marginal add-on but as a powerful cognitive mediator that can revitalise practical science—provided it is supported by sustained, pedagogically focused professional development and reliable classroom technology.

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1. Introduction

1.1. The Enduring Challenge of Practical Work in Science

For decades, practical work has been considered a cornerstone of science education, yet its pedagogical value remains a subject of intense debate. A substantial body of scholarship argues that practical work is a key element of learning science, intended to motivate students, develop experimental skills, and support theoretical understanding. However, there is a persistent critique that many school-based practicals fail to achieve these aims. These activities are often criticised for being too short, lacking authenticity, and failing to motivate or intellectually engage students. All too often, practical lessons devolve into "recipe-following" exercises where students focus on procedural steps to arrive at a predetermined outcome. This process prioritises "hands-on" manipulation over "minds-on" cognitive engagement. This creates a significant disconnect between the physical activities students perform in the laboratory and the scientific concepts they are intended to learn.

1.2. Datalogging Technology as a Pedagogical Intervention

Datalogging technology, also known as probeware, has been available to educators for over three decades as a potential solution to these challenges. By using sensors connected to an interface, datalogging systems automate the process of data collection and generate real-time graphical representations of the phenomena being observed. This technological intervention holds the potential to shift the nature of practical work fundamentally. By offloading the cognitive burden associated with manual data recording and graph plotting, students can dedicate more of their limited class time to higher-order cognitive tasks such as analysis, interpretation, prediction, and discussion. Despite these affordances, the adoption of datalogging in schools has been inconsistent, and there remains a need to understand its perceived effectiveness from the perspective of educators who implement it.

1.3. Research Aims and Guiding Questions

The overarching aim of this study is to investigate teachers' perceptions of whether using datalogging technology in laboratory practical work fosters a higher level of student engagement and higher order thinking than traditional methods of science practical work alone. To structure this inquiry, the research is guided by three specific questions.

1. Is the use of datalogging more effective in promoting higher-order thinking and problem-solving? (RQ1)
2. Can using datalogging help students better understand what the teacher intends for them to grasp? (RQ2)
3. Is using datalogging more effective than traditional practical methods in helping students to understand the concepts of science better? (RQ3)

This paper presents the findings of a large-scale international survey designed to answer these questions, contextualised within a theoretical framework for effective practical work.

2. Literature Review

2.1. The Role and Aims of Practical Work

Practical work is a distinctive and much-anticipated feature of science teaching, and historically it has served many different aims. A seminal 1963 study by Kerr (1963) identified ten potential aims, including encouraging accurate observation, promoting scientific thought, and developing manipulative skills. More recent scholarship often distils these down to four primary goals: motivating students, developing experimental skills, simulating the work of a "real" scientist, and supporting theoretical understanding. The assumption that a hands-on approach is inherently a "good thing" stems largely from its perceived potential to motivate and engage students.

2.2. Critiques of Traditional Practical Work

Despite its central role, the effectiveness of traditional practical work has been widely questioned. Modern critiques often centre on its lack of "authenticity" and its failure to intellectually engage students. Studies have shown that practical lessons are often too short, and students frequently get lost in the procedural details of an experiment—the "recipe"—at the expense of understanding the underlying scientific concepts. This creates a disconnect between the physical actions students perform and the scientific ideas they are meant to be learning. This gap is a central problem that pedagogical interventions seek to address.

2.3. Socio-Constructivism and Inquiry-Based Learning

In response to the limitations of traditional methods, many educational systems have recommended a shift toward an inductive, inquiry-based approach to science education (IBSE). This pedagogical shift is rooted in a socio-constructivist view of learning, which posits that learners construct meaning through active engagement and social interaction. Rather than being passive recipients of information, students in an IBSE model are encouraged to ask questions, conduct investigations, and interpret data, much like professional scientists. In this context, the teacher's role evolves from that of an instructor to a facilitator who guides the learning process. Recent research continues to highlight that technology integration is a key factor in realising the full benefits of IBSE.

2.4. Datalogging as a Technological Solution

Datalogging technology, or "probeware," has emerged as a powerful tool to support inquiry-based learning and address the shortcomings of traditional practicals. By automating data collection and processing, datalogging offers several key affordances that can transform the learning experience. One of the most significant advantages of datalogging is the "immediate link between the investigation and the result". As a phenomenon unfolds, a graph is plotted in real time, helping students make a direct connection between the physical event and its abstract, symbolic representation. This rapid feedback loop, combined with the accuracy and speed of data capture, is challenging to achieve with manual methods and is crucial for bridging the gap between observation and conceptual understanding. Studies have consistently shown that this immediacy increases student motivation and engagement.

Data-logging products have been traditionally deployed in science laboratories (Cleaves & Toplis, 2008) for recording and handling experimental data as part of the National Curriculum for England, amongst others (Deaney, Hennessy, & Ruthven, 2006). When students use dataloggers they avoid the "drudgery of data collection and processing to enable progression to higher order skills" (Cleaves & Toplis, 2008). Early studies (Barton, 1997; Newton, 1997, 1998, 1999; Newton, 2000; Thornton & Sokoloff, 1998) indicate that dataloggers were seen to be useful in supporting experimentation and collaborative group learning because they freed up more time dispensing with the need to manually collect data, draw graphs and process results (Deaney et al., 2006). In particular, dataloggers provide an "immediate link between the investigation and the result" (Barton, 1997) which is consistent with more recent studies (for example, Davies, Collier, and Howe (2012)). The immediacy of the data appearing on the screen helps make a better connection between the experiment and the graph and leads to an increase in student motivation (Barton, 1997; Beichner, 1990; Davies et al., 2012; Mokros & Tinker, 1987; Walshe, 2003; Wellington, 2002; Wellington & Ireson, 2008). Moreover, Warwick and Siraj-Blatchford (2006) found that students who collected data themselves stimulated their desire to provide explanations for their data, and were more likely to discuss their findings with other students (Dempsey, 2010) thereby supporting a socio-constructivism pedagogy. Moreover, Scanlon (2003) Scanlon (2003) explains the shift in focus from the mechanics of taking data and drawing graphs to the development of scientific understanding and higher order thinking was mediated and supported by dataloggers. In a similar study, Cleaves and Toplis (2012) found that dataloggers supported exploration and experimentation and that it afforded more time to discuss results achieved in class. Furthermore, the graphs obtained using dataloggers was more likely to "better represent those seen in the pupils' books and tests" (ibid, p. 207). Moreover, Murphy (2003) comments that the potential afforded by data-logging in primary science is also considerable in terms of prediction, real time data capture, observational skills, space-time cognition, measurement skills and interpretation of data. Deaney et al. (2006) states that the use of dataloggers in science teacher and learning enables "a higher level of analysis to take place than would otherwise be the case". Furthermore, the Ofsted report particularly reflected the contribution of dataloggers to "focus more quickly on the graphical results of their science experiments" (Becta, 2003). In an analysis carried out by Thomas and Banks (2009) major criticisms of university practical work centred on the uninspiring, disconnected, seemingly irrelevant, laboriously long practical that add little to the students' understanding of concepts. Dataloggers may have a role to play in fostering a greater level of engagement and authenticity for the university science student according to a study of 47 first-year physics students in Australia (Rodrigues, Pearce, & Livett, 2001). The study suggests that students were better motivated in performing the experiments and were better able to understand physics concepts.

In his study of 5 schools, Newton (2000) reports that teachers, who were experienced ICT users, looked beyond the mandatory requirements of the National Curriculum and wanted their students to engage with present day technology and to make data collection more meaningful. The argument for students to practice "scientific method" as a means of to achieve a higher "scientific literacy" through "hands-on" has also been argued by McGinn and Roth (2004) as necessary for discovery of the natural world and an insight in what "real" scientists do. The challenges of teaching science is predicated on the myth of what is the real work of scientists, and datalogging can go some way to bridging that knowledge gap. The "authentic science" posited by McGinn and Roth (2004) needs "students to pursue their activities under the constraint that they make their actions and products accountable to themselves" (p. 105). The net result is that a classroom becomes a community of science knowledge building, not dissimilar to scientific communities in professional science (McGinn & Roth, 2004).

2.4.1. Cognitive Offloading and Higher-Order Thinking

By automating what has been called the "drudgery of data collection and processing," datalogging frees students' limited cognitive resources. Instead of focusing on reading scales, recording numbers, and plotting points, students can allocate their mental energy to higher-order skills such as analysing trends, interpreting the meaning of the graph, and discussing their findings. This shift from procedural tasks to analytical ones is a key mechanism for fostering deeper conceptual understanding.

2.4.2. Fostering Collaboration and "Authentic Science"

The shared, dynamic visual display of data on a screen provides a natural focal point for group discussion, prediction, and joint interpretation. This supports a socio-constructivist environment where understanding is co-constructed through dialogue, or "science-talk". Furthermore, by allowing students to take ownership of their data and engage in the processes of scientific inquiry, datalogging can provide a more "authentic science" experience, where students feel like genuine investigators. This sense of authenticity is a powerful motivator and helps students connect their classroom activities to the broader world of science. However, successful integration requires more than by teachers and often requires dedicated professional development.

2.5. A Theoretical Framework for Effective Practical Work

2.5.1. The Aims and Critiques of Practical Science

The role of practical work in science instruction has been conceptualised in various ways. A seminal study by Kerr (1963) identified ten possible aims as ranked by science teachers, including fundamental goals such as encouraging accurate observation, promoting scientific methods of thought, and developing manipulative skills. While these aims remain relevant, modern critiques frequently highlight a failure in execution. The emphasis on procedural correctness often overshadows conceptual development, and a lack of "authenticity" can diminish student motivation and engagement. The central challenge, therefore, is not in defining the potential aims of practical work, but in designing and implementing activities that effectively achieve them.

2.5.2. The Millar and Abrahams Model: Bridging Two Domains

To address this challenge, this study is underpinned by the conceptual model proposed by Millar and Abrahams (2009) which provides a robust framework for evaluating the effectiveness of practical work (Figure 1). The model posits that the primary purpose of a practical activity is to help students make links between two distinct domains:

- The domain of objects and observables, which encompasses the physical equipment students manipulate and the phenomena they observe.
- The domain of ideas, which includes the scientific concepts, theories, and models that the teacher intends for the students to learn.

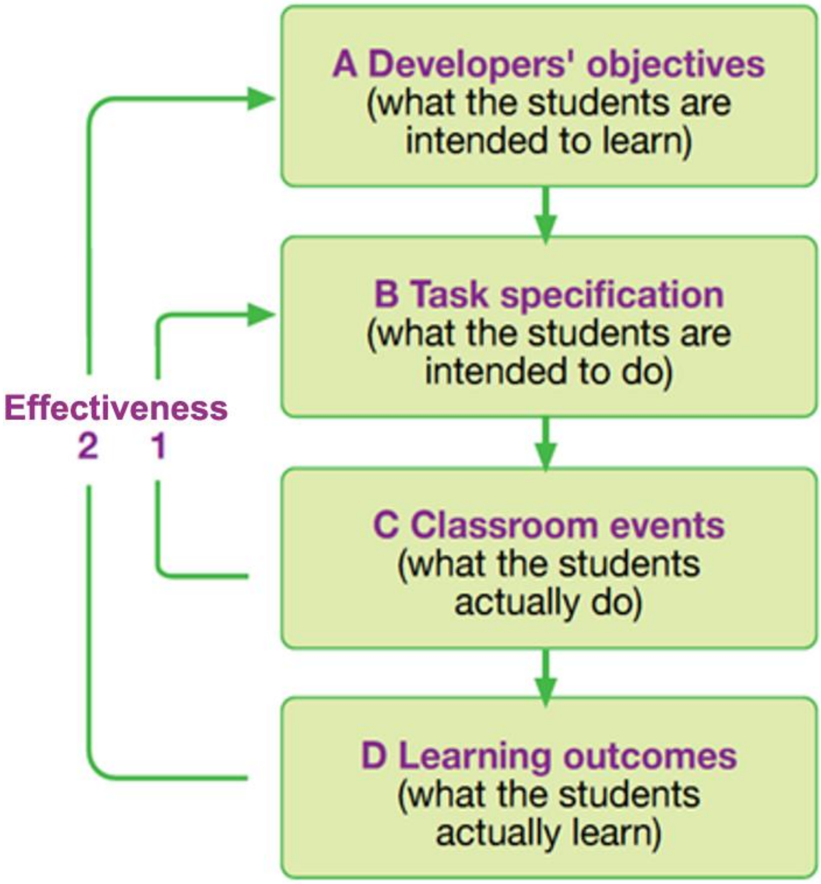

Figure 1. Effectiveness of a teaching and learning activity.

Source: Millar and Abrahams (2009).

According to this framework, a practical task is only effective if it successfully bridges the gap between these two domains. Millar and Abrahams (2009) further delineate two senses of effectiveness for evaluating this process.

1. Effectiveness in Sense 1 (Procedural Success): This relates to whether students do what was intended with the objects and observe what they were meant to observe. It measures the link between the *task specification* and the actual *classroom events*.
2. Effectiveness in Sense 2 (Conceptual Learning): This relates to whether students, during and after the activity, think about what they are doing using the intended scientific ideas. It measures the link between the *developer's objectives* and the actual *learning outcomes*.

The basis of the Millar and Abrahams (2009) framework is measure value in learning science for the students in science practicals by connecting the two "senses" of effectiveness (Figure 1) with the domains of "objects and observables" and "ideas" in science practical work (Figure 2).

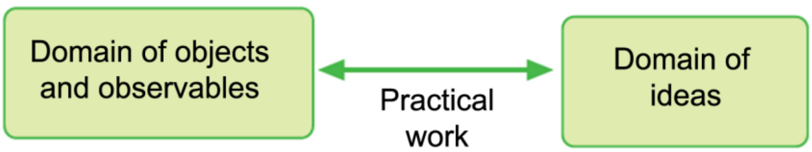

Figure 2. Linking the two domains by practical work.

Source: Millar and Abrahams (2009).

This study argues that traditional practical work often succeeds only in the first sense, while failing in the second. It proposes a refinement of the model, hypothesising that datalogging technology is a particularly powerful intervention for achieving Effectiveness in Sense 2, thereby more effectively closing the gap between the domain of observables and the domain of ideas.

2.5.3. Datalogging's Affordances in a Socio-Constructivist Context

The potential of datalogging to enhance practical work can be understood through a socio-constructivist lens, which emphasises that learners construct meaning through social interaction and active engagement. Datalogging aligns with this paradigm and supports inquiry-based learning (IBL) through several key affordances.

First, the technology provides an immediacy and visualisation that is difficult to achieve with traditional methods. The "immediate link between the investigation and the result," where a graph is plotted in real-time as a phenomenon occurs, helps students make a direct connection between the physical event and its abstract, symbolic representation. This rapid feedback loop is crucial for bridging the two domains described by Millar and Abrahams (2009).

Second, datalogging facilitates cognitive offloading. By automating what Jerry Wellington (2005) referred to as the "drudgery of data collection and processing," the technology frees students' limited cognitive resources. Instead of focusing on reading scales, recording numbers, and plotting points, students can allocate their mental energy to higher-order skills such as analyzing trends, interpreting the meaning of the graph, and discussing their findings.

Finally, this shift in focus fosters "science-talk" and collaborative knowledge building. The shared, dynamic visual display of data on a screen becomes a natural focal point for group discussion, prediction, and joint interpretation. This supports a socio-constructivist environment where understanding is co-constructed through dialogue and shared experience.

2.6. Research Design and Analytical Approach

2.6.1. Research Paradigm and Design

The research adopted a post-positivist philosophical stance. This paradigm acknowledges that complete objectivity is impossible and that the researcher's experience brings a valuable interpretive lens, while still adhering to rigorous, evidence-based methods to draw conclusions from quantitative data. The study employed a large-scale, cross-sectional survey design to capture the perceptions of a broad and geographically diverse sample of science educators.

2.6.2. Sample and Data Collection

The sampling frame for the study was extensive. An online questionnaire was distributed via email to a total of 62,340 named science teachers across five English-speaking regions: the United Kingdom, the United States, Australia, Ireland, and New Zealand. These regions were selected due to the maturity of their science curricula and the significant body of existing scholarship on datalogging within their educational systems. The survey yielded 2,126 valid and complete responses for analysis. To mitigate sampling bias and enhance the generalizability of the findings, the contact list was compiled from two sources: a proprietary database of known technology users and purchased generic lists of science teachers, ensuring the sample was not skewed exclusively towards avid proponents of datalogging.

2.6.3. The Survey Instrument

The questionnaire was developed through a multi-stage validation process to ensure its reliability and validity. An initial draft was reviewed by a small group of 12 teachers from the target regions to refine wording and ensure cross-cultural clarity. This was followed by a formal pilot test with teachers in Ireland (N=436) and Australia (N=525) to test the instrument's statistical properties. The final instrument consisted of two sections: one collecting nominal demographic data to be used as independent variables (e.g., teaching experience, subject taught, school type) and a second section comprising 21 statements about datalogging, rated on a 5-point Likert scale, which formed the dependent variables of the study.

2.6.4. Quantitative Analysis Strategy

A two-phase quantitative analysis strategy was employed to systematically analyse the data.

1. Exploratory Factor Analysis (EFA): The initial phase used EFA to explore the underlying structure of the 21 Likert-scale items. The purpose of this technique was to identify latent constructs by grouping correlated variables, thereby reducing the data into a smaller set of meaningful, coherent themes. The determination of the optimal number of factors was guided by multiple criteria, including Kaiser's criterion (retaining factors with eigenvalues > 1), inspection of scree plots, and Horn's Parallel Analysis, a robust method that compares actual eigenvalues against randomly generated ones to prevent the over-extraction of factors.
2. Multiple Regression Analysis (MRA): The second phase employed MRA to investigate the predictive relationships between variables. This allowed the analysis to move beyond simple correlation to determine the unique, statistically significant contribution of various independent variables (such as teaching subject, brand of equipment used, and time spent on practical work) to the dependent variables clustered within the factors identified by the EFA. The "forced entry" method was used, where all predictors are entered into the model simultaneously, a technique recommended for theory testing as it assesses the contribution of each variable while controlling for all others.

2.7. Findings: Teacher Perceptions of Datalogging's Role

2.7.1. Descriptive Overview of the Sample

The 2,126 respondents represented a diverse cross-section of science educators. The majority were full-time teachers (93%) in mixed-gender schools (68%). The sample included a wide range of teaching experience, with the largest cohorts having taught for 10-19 years (33%) or more than 20 years (40%). The distribution of subject specialisms was relatively even among physics (40%), chemistry (43%), and biology (41%), with a smaller group identifying with STEM (18%). A summary of key demographic data is presented in Table 1.

Table 1. Summary of respondent demographics.

Characteristic	Distribution
Region	USA: 73%, UK: 14%, Australia: 6%, Ireland: 5%, New Zealand: 3%
School size	>1000 students: 34%, 700-999 students: 18%, 500-699 students: 17%
Teaching experience	>20 years: 40%, 10-19 years: 33%, 5-9 years: 18%, 1-4 years: 9%
Main subject taught	Chemistry: 43%, Biology: 41%, Physics: 40%, STEM: 18%
Time on Practicals	Up to 25%: 40%, Up to 50%: 36%, More than 50%: 24%

2.7.2. Identifying Latent Constructs: Exploratory Factor Analysis

The EFA was conducted to identify the underlying themes in teachers' perceptions. The Kaiser-Meyer-Olkin measure of sampling adequacy was .873, well above the recommended value of .6, and Bartlett's Test of Sphericity was significant ($p < .005$), confirming the data's suitability for factor analysis. A parallel analysis indicated that a four-factor solution was optimal, collectively explaining 51% of the total variance. The analysis revealed two particularly strong and coherent factors, as shown in Table 2.

Table 2. Summary of exploratory factor analysis (Oblimin rotation).

Item	Factor 1: Facilitator	Factor 2: Apprehension
Datalogging makes experiments more open-ended and investigative.	**0.72**	
Datalogging is better for inquiry-based approaches.	**0.66**	
Giving ownership of data to students builds on prior knowledge.	**0.62**	
It is easier for the teacher to highlight practical objectives.	**0.59**	
It is easier to convey scientific ideas to students.	**0.55**	
Students are better able to grasp scientific concepts.	**0.52**	
Students are better able to understand graphs.	**0.47**	
Datalogging helps students understand what I want them to.	**0.36**	
Datalogging helps develop scientific knowledge more easily.	**0.35**	
I find dataloggers time-consuming and difficult to set up.		**0.70**
Dataloggers can be unreliable to use.		**0.62**
I find it harder to have students perform the experiment my way.		**0.59**
Datalogging adds more complexity to an experiment.		**0.59**
Eigenvalue	5.47	1.93
% of variance explained	28.78	10.13
Cronbach's Alpha (\alpha)	0.87	0.74

Note: **All predictors listed are statistically significant ($p < 0.05$).

- Factor 1: Datalogging as a "Facilitator" of Learning: This dominant factor grouped nine positively worded items that all relate to the pedagogical benefits of datalogging. It reflects a strong, unified perception that the technology facilitates deeper learning, inquiry, and conceptual understanding. The high internal consistency (Cronbach's \alpha =.87) confirms that these items measure a single underlying construct.
- Factor 2: Teacher "Apprehension" and Practical Challenges: This second factor grouped four negatively worded items related to the practical difficulties of using the technology. It captures teachers' concerns about usability, reliability, and the potential for classroom disruption. Its emergence as a distinct and coherent factor (Cronbach's \alpha =.74) is a significant finding, highlighting the practical barriers that may inhibit adoption.

2.7.3. Predicting Outcomes: Multiple Regression Analysis

Multiple regression analysis was used to determine which independent variables were significant predictors of the outcomes related to the three research questions. The findings reveal that the effectiveness of datalogging is not solely a property of the tool itself but is deeply influenced by the pedagogical context in which it is used. The amount of class time dedicated to "hands-on" activities and the specific science subject being taught consistently emerged as powerful predictors of positive outcomes, suggesting that datalogging acts as a powerful catalyst within a supportive educational ecosystem. A summary of key predictors is presented in Table 3.

Table 3. Key predictors of pedagogical outcomes from multiple regression analysis.

Research question	Key dependent variable (DV)	Most significant predictors (Standardized beta, \beta)
RQ1: Higher-order thinking	DV1.4: Makes experiments more open-ended and investigative.	Male Teacher (\beta=.127), STEM Teacher (\beta=.104), 100% Hands-on Time (\beta=.101)
	DV1.7: Builds on prior knowledge.	100% Hands-on Time (\beta=.205), 50% Hands-on Time (\beta=.218), STEM Teacher (\beta=.085)
RQ2: Teacher-student understanding	DV1.3: Easier to highlight objectives.	100% Hands-on Time (\beta=.172), 50% Hands-on Time (\beta=.158), Vernier Brand (\beta=.085)
	DV1.9: Easier to convey scientific ideas.	Male Teacher (\beta=.248), 50% Hands-on Time (\beta=.224), 100% Hands-on Time (\beta=.189)
RQ3: Conceptual understanding	DV1.1: Develops scientific knowledge.	100% Hands-on Time (\beta=.212), 50% Hands-on Time (\beta=.193), Male Teacher (\beta=.918)*
	DV1.6: Students better understand graphs.	50% Hands-on Time (\beta=.232), 25% Hands-on Time (\beta=.204), Male Teacher (\beta=.190)

Note: *. All predictors listed are statistically significant ($p < .05$). *The extremely high beta for Male Teacher in DV1.1 suggests strong multicollinearity in that specific model, but the variable was consistently significant across multiple models.*

A notable pattern emerges from the analysis: a tension between the pedagogical goals of inquiry and the practicalities of classroom management. Teachers strongly perceive that datalogging makes experiments more "open-ended and investigative" (DV1.4), a key component of higher-order thinking. Yet, they also report that it can be "harder to have the students perform the experiment the way I want them to" (DV2.1). These are not contradictory findings; rather, they expose a core challenge of inquiry-based teaching. The very features that empower students to investigate authentically—speed, automation, and ownership of data—also enable them to deviate from a prescribed procedure. This highlights a critical need for professional development focused not just on the technical use of the tool, but on the pedagogical shift required to manage productive, student-led inquiry.

3. Discussion: Datalogging as a Mediator Between

3.1. Re-examining the Research Questions

The findings provide affirmative, perception-based answers to all three research questions, suggesting that datalogging is a valuable pedagogical tool.

- In relation to RQ1 (Higher-Order Thinking), the results indicate that datalogging is effective because it fundamentally transforms the practical task. Automating data collection shifts the student's role from technician to analyst. The focus moves from the procedural act of measuring to the cognitive act of interpreting, questioning, and drawing conclusions from the data presented, which are the hallmarks of higher-order thinking.
- Regarding RQ2 (Teacher-Student Understanding), datalogging appears to enhance communication by creating a shared, objective, and immediate artifact for discussion: the real-time graph. This visual representation serves as a concrete bridge between the teacher's abstract explanation and the student's concrete observation. It provides a common ground for dialogue, allowing teachers to more easily highlight objectives and convey scientific ideas.
- For RQ3 (Conceptual Understanding), the improvement in understanding is a direct consequence of the technology's ability to forge a tight link between action and consequence. When students see a graph of temperature versus time being plotted as a substance cools, they are not just collecting data points; they are observing a visual narrative of a scientific principle. This real-time connection between the domain of observables and the domain of ideas is what appears to make the learning more effective and the concepts more tangible.

3.1.1. Integrating the Findings with the Millar and Abrahams Model

The study's findings not only support but also enrich the Millar and Abrahams (2009) model by identifying a specific mechanism—datalogging—that enhances both senses of effectiveness.

- Enhancing Sense 1 (Procedural Success): Datalogging helps students "do what was intended" by focusing their attention on the scientific phenomenon itself, rather than on the intricate mechanics of measurement and recording. This clarity of purpose increases the likelihood that students will make the key observations the teacher intended.

- Enhancing Sense 2 (Conceptual Learning): The technology's most profound impact is on the second sense of effectiveness. It powerfully helps students "think about what they are doing" by providing immediate graphical feedback that explicitly links their actions (the observables) to the underlying scientific principles (the ideas). This immediate translation of physical events into abstract representations effectively closes the cognitive gap that often plagues traditional practical work. The research suggests that datalogging acts as a cognitive mediator, making the invisible patterns in the data visible and, therefore, understandable.

3.1.2. Datalogging in the Context of Traditional Aims

The benefits of this modern technology can also be mapped back to the foundational aims of practical work identified over half a century ago. As shown in Table 4, datalogging provides a contemporary means of achieving the long-standing goals of science education.

Table 4. Mapping datalogging affordances to Kerr (1963) Aims of practical work.

Kerr (1963) **Aim**	**How datalogging addresses the aim (Relevant finding)**
1. To encourage accurate observation and careful recording.	Datalogging automates accurate recording, allowing students to focus on observing the phenomenon and the resulting data patterns (DV1.9: Easier to convey ideas).
2. To promote simple, common-sense, scientific methods of thought.	By providing immediate data, it helps students develop scientific knowledge more easily by linking cause and effect (DV1.1).
3. To be an integral part of finding facts by investigation.	The technology facilitates the grasping of scientific concepts by making the data from investigations immediately accessible for analysis (DV1.8).
4. To elucidate the theoretical work so as to aid comprehension.	Datalogging makes it easier for teachers to highlight the main objectives and link the practical activity to theory (DV1.3).
6. To arouse and maintain interest in the subject.	By giving students ownership of their data, datalogging helps build on prior knowledge and maintain interest (DV1.7).

Note: **All predictors listed are statistically significant ($p < 0.05$).

This mapping demonstrates that datalogging is not a departure from the core goals of practical science but rather a more efficient and effective tool for achieving them.

4. Conclusion and Implications for Science Education

4.1. Summary of Findings and Contribution

The overarching question that motivated this research was whether datalogging technology fosters a higher level of engagement and higher-order thinking than traditional methods of science practical work alone. The collective voice of over two thousand science teachers, analysed through a robust statistical framework, provides a clear and affirmative answer. While practical work remains an indispensable cornerstone of science education, its traditional form often fails to achieve its core pedagogical goals. This study has demonstrated that teachers view datalogging technology not as a mere incremental improvement, but as a catalyst for a fundamentally more effective way of teaching and learning science.

By automating the mundane mechanics of data collection and providing immediate, intuitive, and visual feedback, datalogging frees up the cognitive space for students to engage in the authentic practices of science: to question, to analyse, to interpret, and to discuss. It powerfully and effectively bridges the critical gap between doing an experiment and understanding its scientific meaning, a gap that has long hindered the effectiveness of school science.

However, the study also issues a critical warning. This immense potential can only be fully realized if the significant barriers of teacher apprehension—rooted in legitimate concerns about equipment reliability, usability, and inadequate training—are systematically dismantled. The path forward is not simply about acquiring more technology; it is about cultivating an ecosystem of support. This requires a concerted effort from all stakeholders: a commitment to providing teachers with high-quality, intuitive tools and, most importantly, empowering them with the sustained, pedagogy-focused professional development they need to confidently and creatively integrate these tools into their practice. If these conditions are met, datalogging technology is poised to play a vital role in revitalizing practical science, making it a more engaging, authentic, and conceptually rich experience for a new generation of learners.

This large-scale international study provides strong empirical evidence, based on the perceptions of practising science teachers, that datalogging technology is a powerful pedagogical tool for overcoming many of the traditional limitations of practical science. The findings show that teachers perceive datalogging as a strong predictor of increased student engagement, improved conceptual understanding, and the promotion of higher-order thinking. The primary contribution of this research is the demonstration of how datalogging acts as a cognitive mediator, effectively bridging the gap between the concrete "domain of objects and observables" and the abstract "domain of ideas," as conceptualised by Millar and Abrahams (2009).

4.2. Implications for Practice and Policy

The findings have clear implications for educators and policymakers.

- For Practitioners: Teachers should be encouraged to integrate datalogging not as a replacement for foundational skills, but as a tool to elevate the cognitive demand of practical work. The goal should be to use the technology to shift the focus from data collection to data analysis, discussion, and interpretation.
- For School Leaders and Policymakers: The emergence of the "Apprehension" factor is a critical finding. It indicates that simply providing the technology is insufficient. Any investment in datalogging must be accompanied by a robust and sustained commitment to high-quality professional development. This training must address not only the technical operation of the equipment but also the pedagogical shifts required to manage inquiry-based learning effectively. Overcoming teachers' legitimate concerns about reliability, setup time, and classroom management is paramount to successful implementation.

4.3. Limitations and Future Research Directions

The conclusions of this study should be considered in light of its limitations. The primary limitation is its reliance on self-reported teacher perceptions rather than direct, objective measures of student outcomes. While teacher perception is a valuable and valid area of inquiry, it provides an indirect measure of student learning. Therefore, future research should build upon these findings with studies that:

1. Employ mixed-methods designs that triangulate teacher survey data with classroom observations and direct assessments of student performance to validate these perceptions.
2. Conduct comparative studies that systematically examine the impact of different types, brands, and qualities of datalogging equipment on learning outcomes.
3. Undertake longitudinal research to track the long-term effects of sustained datalogging use on students' scientific literacy, inquiry skills, and attitudes toward science.

By pursuing these avenues, the educational research community can build a more complete picture of how-to best leverage technology to make practical science a truly "minds-on" experience for all students.

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