Perceptions of Research Process Presentations: Credibility and Tentativeness of Research Findings

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In liebevoller Erinnerung an meinen Opa
sowie in Dankbarkeit an meine Familie.

Contents

SUMMARY VII

ZUSAMMENFASSUNG VIII

LIST OF TABLES IX

LIST OF FIGURES X

1. GENERAL INTRODUCTION 1

1.1 Scientific Knowledge in Context: Understanding Tentativeness and Credibility 2
1.2 The Project VideT 5
1.3 Focus of the Present Work 6
1.4 Structure and Objectives of the Dissertation 7

2. OPENING THE BLACK BOX OF SCIENTIFIC PRACTICES – A SYSTEMATIC VIDEO DEVELOPMENT FRAMEWORK INTEGRATING SCIENTIFIC REASONING SKILLS AND INSIGHTS INTO AUTHENTIC RESEARCH PROCESSES 9

2.1 Introduction 10
2.2 Theoretical Background 12
2.2.1 Authentic Science in Science Class – Both Goal and Black Box? 15
2.2.2 Using Videos to Make the Work and Thinking of Scientists Visible to Students 17
2.3 The Systematic Video Development Framework 19
2.3.1 Macro Level: The Foundational Structure 20
2.3.2 Meso Level: Authentic Cases of Scientific Research Processes 22
2.3.3 Micro Level: Building Blocks for Video Variations 23
2.3.3.1 Presentation of Scientific Practices on the Micro Level 23
2.3.3.2 Presentation of Scientists' Thought Processes on the Micro Level 24
2.4 How Does the Video Development Framework Advance Research in Science Education? Discussion and Implications for Research 27
2.5 How do Science Lessons Benefit from the Video Development Framework? Educational Implications 29
2.6 Conclusion 30

3. RESEARCH PROCESS PRESENTATIONS IN SCIENCE EDUCATION: PERCEPTIONS OF CREDIBILITY AND TENTATIVENESS IN RESEARCH FINDINGS 33

3.1 Introduction 34
3.1.1 Scientific Inquiry and Communication: Bridging Uncertainty and Understanding 37
3.1.2 Scientific Literacy as a Foundation 37
3.1.3 Research Objectives and Design 39
3.1.4 Present Research and Hypotheses 42
3.1.4.1 Perception of the Scientist's Credibility 42
3.1.4.2 Perception of the Credibility of Research Findings 42
3.1.4.3 Perceived Tentativeness of Research Findings 42
3.1.5 Ethics Statement 43
3.1.6 Power Analysis 43
3.2 Study 1: Text-Based Presentation 44
3.2.1 Methods 44
3.2.1.1 Sample 44
3.2.1.2 Design and Procedure 45
3.2.2 Material and Measures 46
3.2.2.1 Text-Based Presentation 46
3.2.2.2 Perception of the Scientist's Credibility 47
3.2.2.3 Perception of the Credibility of Research Findings 47
3.2.2.4 Perceived Tentativeness of Research Findings 47
3.2.2.5 Correlation Analysis 48

3.2.3 Results ... 48
3.2.3.1 Hypotheses Testing ... 48
3.2.3.2 Further Analysis: Correlation Analysis ... 49
3.2.4 Discussion ... 49
3.3 Study 2: Video-Based Presentation ... 51
3.3.1 Methods ... 51
3.3.1.1 Objective ... 51
3.3.1.2 Sample ... 51
3.3.1.3 Design and Procedure ... 52
3.3.2 Material and Measures ... 52
3.3.2.1 Video-Based Presentation ... 52
3.3.3 Results ... 53
3.3.3.1 Hypotheses Testing ... 53
3.3.3.2 Further Analysis: Correlation Analysis ... 54
3.3.4 Discussion ... 54
3.4 General Discussion ... 56
3.4.1 Key Findings and Interpretations ... 57
3.4.1.1 Presentation Formats ... 57
3.4.1.2 Credibility and Tentativeness of Research Findings ... 57
3.4.1.3 Educational Implications: Promoting Scientific Literacy ... 58
3.4.1.4 Strengths and Weaknesses of the Studies ... 59
3.4.1.5 Future Directions for Research ... 60
3.4.1.6 Broader Applications ... 61
3.5 Conclusion ... 61

4. SECONDARY SCHOOL STUDENTS' PERCEPTIONS OF CREDIBILITY AND TENTATIVENESS IN RESEARCH PROCESS PRESENTATIONS ... 63

4.1 Introduction ... 64
4.1.1 The Nature of Science and Scientific Reasoning ... 67
4.1.2 Challenges in Science Education and the Need for New Approaches ... 68
4.1.3 The Paradox of Scientific Progress and Uncertainty ... 69
4.1.4 Understanding Uncertainty and Tentativeness in Scientific Inquiry ... 70
4.1.5 Theoretical Rationale and Hypotheses ... 71
4.2 Method ... 72
4.2.1 Design ... 72
4.2.2 Material ... 74
4.2.3 Procedure ... 75
4.3 Study 1 ... 76
4.3.1 Participants ... 76
4.3.2 Measures ... 76
4.3.2.1 Credibility of the Scientist ... 77
4.3.2.2 Credibility of the Research Findings ... 77
4.3.2.3 Perceived Tentativeness of the Research Findings ... 77
4.3.3 Results ... 77
4.3.3.1 Descriptive Statistics ... 77
4.3.3.2 Confirmatory Analyses ... 78
4.3.3.3 Exploratory Analyses ... 78
4.3.4 Discussion ... 79
4.4 Study 2 ... 81
4.4.1 Participants ... 81
4.4.2 Measures ... 82
4.4.2.1 Credibility of the Scientist ... 82
4.4.2.2 Credibility of the Research Findings ... 82
4.4.2.3 Perceived Tentativeness of the Research Findings ... 82
4.4.2 Results ... 82
4.4.2.1 Descriptive Statistics ... 82
4.4.2.2 Confirmatory Analyses ... 83
4.4.2.3 Exploratory Analyses ... 84
4.4.3 Discussion ... 85

4.5 General Discussion ... 86
4.5.1 Theoretical Implications ... 87
4.5.2 Limitations and Future Research ... 88
4.5.3 Implications for Science Education ... 89
4.6 Conclusion ... 91

5. UNDERSTANDING SCIENTIFIC TENTATIVENESS THROUGH BAT ECOLOGY: A VIDEO-BASED STUDY TO PROMOTE SCIENTIFIC LITERACY IN WILDLIFE RESEARCH ... 93

5.1 Introduction ... 94
5.1.1 Theoretical Framework ... 95
5.1.1.1 Science-in-the-Making versus Ready-Made Science ... 96
5.1.1.2 Cookbook-Style versus Scientific Reasoning Style in Wildlife Research ... 96
5.1.1.3 Communicating Epistemic Principles ... 97
5.1.1.4 Presentation Style, Researcher Portrayal, and Video Formats ... 97
5.1.1.5 Academic Self-Efficacy and Epistemic Processing ... 98
5.1.2 Research Hypotheses ... 98
5.1.2.1 Portrayal of Scientists and Credibility ... 98
5.1.2.2 Presentation of Research Processes ... 99
5.1.2.3 Individual Differences in Academic Self-Efficacy ... 99
5.1.2.4 Hypotheses ... 99
5.2 Method ... 100
5.2.1 Study Design and Sample ... 100
5.2.2 Experimental Design ... 100
5.2.3 Measures ... 101
5.2.3.1 Perceived Credibility of the Scientist ... 101
5.2.3.2 Perceived Credibility of the Research Findings ... 101
5.2.3.3 Perceived Tentativeness of the Research Findings ... 101
5.2.3.4 Academic Self-Efficacy ... 102
5.2.4 Procedure and Exclusion Criteria ... 102
5.2.5 Sample Size Determination and Randomization ... 102
5.3 Results ... 102
5.3.1 Perceived Credibility of the Scientist (H1) ... 102
5.3.2 Perceived Credibility of the Research Findings (H2) ... 103
5.3.3 Perceived Tentativeness of the Research Findings (H3) ... 103
5.3.4 Academic Self-Efficacy and its Predictive Role (H4–H5) ... 104
5.3.5 Tentativeness and Credibility (H6) ... 104
5.4 Discussion ... 106
5.4.1 Summary of Findings ... 107
5.4.2 Role of Academic Self-Efficacy ... 108
5.4.3 Practical Implications ... 108
5.4.4 Methodological Strength and Clarification ... 109
5.4.5 Limitations and Future Research ... 110
5.5 Conclusion ... 110

6. GENERAL DISCUSSION ... 112

6.1 Summary of Main Findings ... 112
6.2 Strengths and Limitations ... 113
6.3 Theoretical Implications ... 116
6.4 Practical Implications ... 117
6.5 Future Research Directions ... 119

7. CONCLUSION ... 120

REFERENCES ... 122

Summary

In an era of increasing scientific complexity and public skepticism, the question of how science can be communicated in ways that are both transparent and trustworthy has become more urgent than ever. Scientific findings are often perceived as definitive, despite their inherently provisional nature. This tension can lead to misunderstandings and diminished trust in science communication. By addressing this challenge, the present dissertation investigates how the presentation of scientific research processes influences perceptions of tentativeness and credibility in educational and public contexts.

As part of the interdisciplinary project VideT, a video-based transfer instrument was developed to visualize authentic research processes in the field of bat ecology. Across three empirical study packages, the dissertation systematically varied media formats (text vs. video), target groups (university students, secondary school students, general public), research contexts (Thailand vs. Germany), materials, and scientist portrayals (male vs. female), while maintaining a consistent overarching research question and identical dependent variables. This design enabled a robust and ecologically valid investigation of how portrayals of scientific reasoning affect audience perceptions.

The findings show that explanatory depth and authentic portrayals of scientists' thought processes increase perceived tentativeness. In student samples (Chapters 3 and 4), tentativeness was negatively correlated with credibility. In contrast, the general public (Chapter 5) perceived tentativeness without a loss of trust, suggesting that uncertainty can be communicated effectively when framed transparently and contextually.

The findings of this dissertation suggest that making the scientific process more visible, by showing how knowledge is generated and justified, can enhance students' understanding of the tentative nature of science. However, this increased transparency may also challenge perceptions of scientific credibility, highlighting a central dilemma for science education and communication. Science communication and education thus face the challenge of making scientific reasoning visible, aiming to foster epistemic awareness without undermining the perceived credibility of scientists and their findings.

Zusammenfassung

In einer Zeit zunehmender wissenschaftlicher Komplexität und gesellschaftlicher Skepsis stellt sich die Frage, wie Wissenschaft so kommuniziert werden kann, dass sie sowohl transparent als auch vertrauenswürdig ist. Wissenschaftliche Erkenntnisse werden häufig als endgültig wahrgenommen, obwohl sie im wissenschaftlichen Diskurs grundsätzlich vorläufig sind. Diese Diskrepanz kann zu Missverständnissen und einem Vertrauensverlust in die Wissenschaftskommunikation führen. Die vorliegende Dissertation widmet sich daher der Frage, wie wissenschaftliche Unsicherheit verständlich vermittelt werden kann, ohne die Glaubwürdigkeit zu mindern.

Im Rahmen des interdisziplinären Projekts VideT wurde ein videobasiertes Transferinstrument entwickelt, das authentische Forschungsprozesse aus dem Feld der Fledermausökologie visualisiert. In drei empirischen Studienpaketen wurden systematisch Medienformate (Text vs. Video), Zielgruppen (Studierende, Schüler:innen, Öffentlichkeit), Forschungskontexte (Thailand vs. Deutschland), Materialien und die Darstellung von Wissenschaftler:innen (männlich vs. weiblich) variiert – bei gleichbleibender übergeordneter Fragestellung und identischen Variablen. Dieses Design ermöglichte eine robuste und ökologisch valide Untersuchung der Frage, wie Darstellungen wissenschaftlichen Denkens die Wahrnehmung von Vorläufigkeit und Glaubwürdigkeit beeinflussen.

Die Ergebnisse zeigen, dass erklärende Darstellungen und authentische Einblicke in Denkprozesse von Forschenden die Wahrnehmung von Vorläufigkeit erhöhen. In den Stichproben mit Studierenden (Kapitel 3 und 4) korrelierte Vorläufigkeit negativ mit Glaubwürdigkeit. In der allgemeinen Bevölkerung (Kapitel 5) konnte Unsicherheit hingegen vermittelt werden, ohne Vertrauen zu verlieren, vorausgesetzt sie wurde transparent und kontextsensibel dargestellt. Die Ergebnisse dieser Dissertation legen nahe, dass eine stärkere Sichtbarmachung wissenschaftlicher Prozesse – etwa durch die Darstellung, wie Wissen generiert und begründet wird – das Verständnis für die Vorläufigkeit wissenschaftlicher Erkenntnisse fördern kann. Gleichzeitig kann diese Transparenz jedoch auch das Vertrauen in die Glaubwürdigkeit von Wissenschaft herausfordern und verweist damit auf ein zentrales Spannungsfeld für Wissenschaftsvermittlung und -bildung. Wissenschaftskommunikation und -bildung stehen damit vor der Herausforderung, wissenschaftliche Denkprozesse sichtbar zu machen – mit dem Ziel, epistemisches Bewusstsein zu fördern, ohne dabei die Glaubwürdigkeit von Wissenschaftlern und ihren Ergebnissen zu gefährden.

List of Tables

Table 1 Exemplary Video Transcript – Scientific Practices ... 24
Table 2 Exemplary Video Transcript – Scientists' Thought Processes ... 26
Table 3 Explanation of the Conditions ... 46
Table 4 Correlation Matrix of Study 1 ... 49
Table 5 Correlation Matrix of Study 2 ... 54
Table 6 Overview of Experimental Conditions ... 74
Table 7 Descriptive Statistics Across Experimental Conditions (Study 1) ... 78
Table 8 Kendall's Tau-b Correlations (Study 1) ... 79
Table 9 Kendall's Tau-b Intercorrelations (Study 1) ... 79
Table 10 Descriptive Statistics Across Experimental Conditions (Study 2) ... 83
Table 11 Kendall's Tau-b Correlations (Study 2) ... 84
Table 12 Kendall's Tau-b Intercorrelations (Study 2) ... 85
Table 13 Correlation Matrix of the Measured Scales ... 105
Table 14 Tentativeness & Credibility (Kendall's Tau-b, by Condition) ... 106

List of Figures

Figure 1 Video Development Framework on Macro, Meso and Micro Level 20

Figure 2 Boxplot of the Perceived Tentativeness of the Research Findings 104

1. General Introduction

In an era of digital information exchange, scientific findings are more visible than ever, circulating through news media, social platforms, classrooms, and policy debates. Yet this increasing accessibility does not necessarily foster deeper understanding. Many individuals struggle to interpret research results, particularly when it comes to recognizing the provisional nature of scientific knowledge and evaluating its credibility (Bromme & Goldman, 2014; Flemming et al., 2020; Kimmerle et al., 2015).

This challenge is especially pressing in educational contexts. International assessments such as PISA consistently show that students often lack a nuanced understanding of how scientific knowledge is generated, revised, and validated (OECD, 2023a). While they may recall factual content, they frequently struggle to evaluate the reliability of sources or grasp the iterative nature of scientific inquiry. Moreover, surveys on public trust in science reveal a paradox: people express general trust in science but are skeptical when findings appear uncertain or contradictory (Algan et al., 2021; Hendriks et al., 2016b; Kreps & Kriner, 2020; National Science Board, 2022; Wintterlin et al., 2022).

This tension between visibility and understanding raises urgent questions: How can science be communicated in ways that are both transparent and trustworthy? How can learners be supported in recognizing uncertainty not as a flaw, but as a hallmark of scientific rigor?

Educational research increasingly addresses these questions by focusing on how science is portrayed, not just as a body of knowledge, but as a process. Representations of *science-in-the-making* emphasize uncertainty, iterative revision, and thought processes, while *ready-made science* presents polished, conclusive results. Both formats shape perceptions: the former may foster epistemic awareness but challenge credibility (Covitt & Anderson, 2022; Hyde, 2025); the latter may enhance trust but obscure the tentativeness of knowledge (de Boer et al., 2021; Latour & Woolgar, 1986; Scharrer et al., 2017).

Science education often reinforces the latter view. Instructional formats frequently emphasize outcomes over processes, leaving students ill-equipped to evaluate the credibility and tentativeness of scientific claims (Kind & Osborne, 2017; Lederman et al., 2002). To address this gap, educational strategies must go beyond content delivery and illuminate the reasoning behind scientific decisions.

This dissertation contributes to this endeavor by investigating how different representations of research processes, particularly video-based formats, affect perceptions of scientific credibility and tentativeness. Drawing on the interdisciplinary project VideT, it explores how authentic portrayals of scientific reasoning can foster epistemic understanding across diverse audiences: university students, secondary school students, and the general public.

The central thesis is that uncertainty in science can be communicated without undermining trust, provided it is framed transparently and contextually. Through a series of empirical studies, this work examines how explanatory depth, portrayal style, and medium influence audience perceptions. It integrates insights from epistemic cognition, multimedia learning, and science education to develop a systematic video development framework that makes the "Black Box" of science visible.

Ultimately, this dissertation argues that fostering scientific literacy requires more than teaching facts, it demands engaging learners with the epistemic foundations of science. If students and citizens are to navigate scientific controversies and make informed decisions, they must learn to appreciate both the strengths and limitations of scientific knowledge. This calls for educational and communicative formats that balance transparency with credibility, and that portray science not as a static product, but as a dynamic, reflective process.

1.1 Scientific Knowledge in Context: Understanding Tentativeness and Credibility

A central challenge in science communication lies in how uncertainty is conveyed. Scientific findings are often presented as finalized and conclusive, while the iterative, revisable nature of inquiry remains obscured (Fischhoff & Davis, 2014; van der Bles et al., 2019). This concealment of epistemic complexity, described by Latour and Woolgar (1986) as the "Black Box" of science, can lead to misinterpretations. Uncertainty is frequently mistaken for unreliability, and evolving findings may erode public trust (Flemming et al., 2020). This became particularly evident during the COVID-19 pandemic, when a widely discussed preprint on the infectivity of children in Germany sparked intense public debate (Jones et al., 2020). As more data emerged, initial findings were revised, resulting in changes to public health recommendations. Although scientifically appropriate, these shifts were perceived by many as inconsistencies, contributing to a decline in trust in scientific expertise (Algan et al., 2021; Kreps & Kriner, 2020; Radrizzani et al., 2023; van der Bles et al., 2019).

Yet, tentativeness is not a flaw but a hallmark of science. It reflects the openness of knowledge to revision, the continuous refinement of hypotheses, and the dynamic interplay between theory and evidence (Bromme & Goldman, 2014; Flemming et al., 2020). Communicating tentativeness transparently can enhance credibility rather than diminish it, especially when the reasoning process behind findings is made visible and invites reflection on the nature of evidence (Hendriks et al., 2016a; Hendriks & Jucks, 2020).

In reality, however, tentativeness is often under-communicated or even deliberately omitted. Scientific findings are frequently presented without reference to their provisional nature, and when uncertainty is addressed, it is sometimes misinterpreted as a sign of unreliability (Flemming et al., 2015, 2020). This communicative gap can have serious consequences: if the revisability of findings is not made explicit from the outset, later corrections or updates may appear inconsistent or untrustworthy to the public. Thus, while acknowledging uncertainty is epistemically honest and essential for scientific literacy, it also poses a communicative challenge. It is therefore crucial not to conceal tentativeness, but to consistently explain it as an integral part of scientific inquiry, so that revisions are understood not as failures, but as signs of a functioning scientific process.

This leads to a core dilemma for science communication: How can the evolving nature of knowledge be conveyed without undermining trust?

Research shows that portrayals of science, either as *ready-made science* (authoritative and conclusive) or as *science-in-the-making* (open, provisional, and uncertain), strongly influence public perceptions (Latour, 1987; Scharrer et al., 2017). *Ready-made science* portrayals tend to foster higher credibility, likely due to their alignment with expectations of expertise and authority. However, they may obscure the tentativeness of scientific knowledge. In contrast, *science-in-the-making* portrayals highlight uncertainty and revision, which can reduce perceived certainty and challenge assumptions of scientific authority (de Boer et al., 2021; Latour & Woolgar, 1986; Scharrer et al., 2017).

This tension raises a fundamental question: Why do people trust scientific claims more when they are presented as facts, even if such presentations omit the underlying reasoning? Is credibility primarily driven by perceived authority, or does transparency in the reasoning process also play a role? These questions are central to understanding how scientific knowledge is evaluated and believed.

Educational practices further reinforce the perception of science as a collection of fixed facts. Science education often emphasizes factual content while neglecting epistemic aspects, leaving students ill-equipped to evaluate the credibility and tentativeness of scientific claims (Kind & Osborne, 2017; Lederman et al., 2002; Sinatra & and Lombardi, 2020). To address this gap, instructional formats are needed that go beyond transmitting outcomes and instead illuminate the process of knowledge generation. Such approaches aim to foster a deeper understanding of the tentativeness of scientific claims, which in turn can enhance perceptions of credibility.

Understanding how individuals perceive and evaluate scientific knowledge requires insight into the cognitive processes underlying these judgements. The field of epistemic cognition has provided valuable frameworks for understanding how people conceptualize knowledge and the process of knowing (Hofer & Pintrich, 1997; Iordanou, 2016). These insights are particularly relevant for science communication, which must not only convey factual content but also foster understanding of how scientific knowledge is generated, evaluated, and revised.

This dissertation builds on these theoretical foundations by examining how different representations of scientific reasoning, particularly those that make epistemic features visible, affect audience perceptions of credibility and tentativeness. By integrating epistemic cognition with multimedia learning and science education frameworks, it offers a nuanced investigation into how scientific uncertainty can be communicated effectively.

At its core, this dissertation argues that authentic portrayals of scientific reasoning, including uncertainties, methodological decisions, and interpretative debates, are essential for strengthening public trust and epistemic understanding. Through a series of empirical studies, it explores how audiences perceive different representations of research processes, with a particular focus on video-based interventions that aim to open the "Black Box" of science.

Trust in science is increasingly recognized as a multidimensional construct, shaped by perceptions of competence, integrity, and benevolence (Hendriks et al., 2016b; Mayer et al., 1995). In the context of communicating uncertainty, transparency becomes a double-edged sword: while it can enhance perceived integrity, it may also challenge assumptions of scientific authority. Although "authority" is not explicitly part of Mayer et al.'s trust model (1995), it is closely related to perceived expertise and legitimacy, key components of competence. This dissertation addresses this tension by exploring how different portrayals of scientific reasoning, from polished, finalized narratives to authentic, deliberative processes, affect trust-related judgments. The findings contribute to ongoing debates about the epistemic foundations of public trust in science and offer practical implications for designing communication formats that balance transparency with credibility.

1.2 The Project VideT

To address the challenges of communicating scientific uncertainty and making research processes more transparent, the interdisciplinary research initiative *VideT – Communicating the Research Process: A Video-Based Transfer Instrument for Secondary School Students* was launched in July 2021 and runs until December 2024. The project brings together expertise from the natural sciences, educational research, and science communication. Collaboration partners include the Leibniz Institute for Zoo and Wildlife Research (IZW) in Berlin, the Leibniz Institute for Science and Mathematics Education (IPN) in Kiel, the Ruhr University Bochum (RUB), the Leibniz University Hannover (LUH) and the Leibniz-Institut für Wissensmedien (IWM) in Tübingen.

VideT develops and evaluates a video-based transfer instrument designed to make empirical research processes accessible to students and lay audiences. Ecological fieldwork on bats in Thailand and Germany serves as the thematic foundation, as it exemplifies systematic, step-by-step data collection and highlights both methodological challenges and interpretative reasoning. This context provides an ideal case for illustrating the iterative and provisional nature of scientific inquiry.

The IWM subproject investigates how different representations of research influence audiences' perceptions of scientific credibility, both with regard to the scientist and the research findings, as well as their perception of the tentativeness of scientific knowledge. It builds on distinctions between representations that focus on scientific outcomes and those that emphasize the reasoning processes underlying them, as well as between portrayals of scientists as authoritative experts or reflective inquirers. These dimensions capture central modes or representing science and provide a framework for analyzing how such portrayals shape public understanding of scientific credibility and the provisional nature of knowledge.

The resulting videos combine scripted sequences, authentic interview segments, and voice-over narration. They were evaluated in school-based interventions across Baden-

Württemberg and subsequently extended to university students and general population samples.

The overarching goal of VideT is to foster scientific literacy by making research processes visible, comprehensible, and relatable. Unlike formats that merely illustrate isolated aspects of science, VideT captures the entire research process, from the initial formulation of research questions to data collection, analysis, and interpretation. Because real-world research unfolds over long periods of time and is rarely accessible to learners or the general public, VideT condenses this process into short, engaging video formats. In doing so, it enables audiences to observe and engage with authentic scientific reasoning in its full complexity. This includes methodological decisions, epistemic uncertainties, and interpretative debates, all presented in a way that maintains narrative clarity without sacrificing epistemic depth.

In this way, VideT contributes to the development of evidence-based strategies for science communication and education, while also promoting the use of video-based (transfer) instruments in schools that make the entire research process visible and tangible for learners, thereby fostering epistemic understanding and trust in science.

1.3 Focus of the Present Work

This dissertation was conducted within the IWM subproject of the VideT initiative and investigates how different portrayals of the research process influence student and public perceptions of scientific tentativeness and credibility. While the individual studies differ in sample, setting, and medium, they are all guided by a consistent overreaching research question:

How do representations of scientific reasoning affect audience perceptions of the tentativeness and credibility of the scientific project?

To address this question in a robust and generalizable manner, the research design incorporated multiple methodological dimensions. First, we developed authentic portrayals of ecological fieldwork in two distinct contexts – bat flight behavior in Thailand and bat responses to light pollution in Germany. These portrayals were initially scripted in text form and subsequently transformed into video materials, ensuring consistency in content and scientific reasoning across formats.

The resulting materials were then used in studies involving different audience groups: university students, secondary school students (in both classroom and lab-institute settings), and members of the general public. Furthermore, we ensured gender balance and diversity in scientific representation by featuring both male and female researchers.

This multi-dimensional design constitutes a key methodological feature of the dissertation. Although the conceptual framework remained constant, it was tested across varied contexts, samples, and materials, thereby enhancing the reliability, robustness, and ecological validity of the findings. In doing so, the project moves beyond isolated case studies and demonstrates the stability of key effects across multiple conditions. Specifically, the study design considered five key dimensions: media format (text and video), target groups (university students, secondary school students, general public), research contexts (Thailand and Germany), materials, and scientist portrayals (male and female). Despite these variations, all studies were guided by a consistent overarching research question and employed identical dependent variables. This methodological consistency across diverse conditions strengthens the internal validity and allows for robust conclusions regarding the effects of scientific reasoning portrayals.

The empirical studies are embedded within a broader theoretical and methodological framework that integrates insights from science education, multimedia learning, and philosophy of science. This framework, introduced in Chapter 2, serves as the conceptual backbone for all subsequent investigations. It enables systematic variation in how scientific practices and thought processes are presented, allowing for controlled comparisons of their effects on audience perceptions.

1.4 Structure and Objectives of the Dissertation

This dissertation contributes to the overarching goals of the VideT project by systematically investigating how different representations of scientific research processes affect perceptions of tentativeness and credibility across diverse educational and public contexts. It is structured into one theoretical and three empirical chapters, each building upon the central research question while extending its scope to new audiences and settings:

- Chapter 2 introduces the systematic video development framework, which integrates scientific reasoning skills and insights into authentic research practices. This framework serves as the conceptual and methodological foundation for all subsequent empirical studies. It outlines the macro, meso, and micro levels of videos design, enabling controlled variation in how scientific practices and thought processes are portrayed.

- Chapter 3 presents two online experiments with university students, examining text-based and video-based representations of bat ecology research conducted in Thailand. The study investigates how explanatory depth and portrayal style influence perceptions of credibility and tentativeness in a controlled setting.
- Chapter 4 extends the investigation to secondary school students, examining how instructional design and video format affect epistemic understanding. Two field studies are conducted: one in classroom settings in Baden-Württemberg, and one in interactive lab-institute environments in North Rhine-Westphalia and Schleswig-Holstein.
- Chapter 5 broadens the scope to the general public, applying the same conceptual framework to a new but thematically related research context – bat responses to light pollution in Germany. In a large-scale online experiment with over 1,000 participants, the robustness of the framework is tested across a heterogenous audience.

Together, these chapters provide a comprehensive and multi-perspective analysis of how research process presentations shape perceptions of scientific credibility and tentativeness. By varying media formats, audience groups, research contexts, and scientist portrayals, while maintaining a consistent theoretical foundation.

2. Opening the Black Box of Scientific Practices – a Systematic Video Development Framework Integrating Scientific Reasoning Skills and Insights into Authentic Research Processes

Statement of Contribution

Author	**Author Position**	**Scientific Ideas %**	**Data Generation %**	**Analysis & Interpretation %**	**Paper Writing**
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Vanessa van den Bogaert[2]	1	20	-	-	35
Miriam Brandt	2	2,5	-	-	2,5
Till Bruckermann	3	15	-	-	5
Hannah Greving	4	15	-	-	5
Ute Harms	5	2,5	-	-	2,5
Joachim Kimmerle	6	2,5	-	-	2,5
Daniel Lewanzik	7	2,5	-	-	2,5
Anke Schumann	8	2,5	-	-	2,5
Julia Cathérine Thomas	9	15	-	-	5
Joachim Wirth	10	2,5	-	-	2,5
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Abstract

Understanding scientific practices is fundamental to our modern society and to science education. Concepts such as *scientific reasoning* and *nature of science* are important to operationalize different aspects of these practices. Educational policy organizations and international standards emphasize the importance of insights into the activities and thought processes of scientists to improve science learning. As the implementation of these requirements in the classroom is a challenging goal, videos are effective tools for making aspects of scientific practices visible that often remain hidden for students. Current approaches in science education tend to adopt either an affective-volitional focus by authentic insights into scientific practices or a cognitive focus by promoting student skills in the context of scientific reasoning or nature of science. In this theoretical contribution, we argue for a synergistic integration of these foci. Following this argument, we derive a systematic framework for video development by combining insights from science education with the contextual analysis of science and technology studies and philosophy, which aims to open the black box of scientific practices while developing videos that systematically address students' skills and provide authentic insights into scientific research processes. In this paper, we present a new systematic framework for video development and provide examples of videos created using this framework for discussion within the scientific community.

2.1 Introduction

Scientific practices play a pivotal role in shaping our modern society, not only through their findings and technological applications but also by influencing how we think, reason, and work (Bucchi & Saracino, 2016; Dickel & Franzen, 2016). Fostering scientific literacy and understanding how scientists think and operate is a central goal in preparing students to navigate an increasingly complex world (Hodson, 2014; National Research Council, 2012; NGSS Lead States, 2013; OECD, 2023b). Concepts such as scientific reasoning and nature of science are essential in this educational endeavor, serving both as learning objectives and as tools for deeper engagement. The development of higher-order thinking skills is integral to this process, enabling learners to critically engage with complex scientific ideas. As scientific reasoning and nature of science are closely linked to epistemic cognition, they also support a more nuanced understanding of scientific concepts and practices (Elby et al., 2016; Reith & Nehring, 2020).

Integrating authentic insights into scientific practices within classroom settings remains both a crucial objective and a significant challenge for science educators. The need to equip students with 21st century skills is increasingly evident (Kind & Osborne, 2017; National Research Council, 2012; NGSS Lead States, 2013; OECD, 2023b). This paper advocates for a synergistic integration of skill-oriented education and authentic representations of scientific practices and introduces an innovative framework for the development of video-based educational materials.

The proposed video development framework aims to open the *Black Box* of scientific practices by illustrating different forms of knowledge (i.e., content knowledge, procedural knowledge, and epistemic knowledge) as well as scientists' thought processes concerning nature of science aspects during research. Central to this initiative is the VideT project, an interdisciplinary effort that developed and applied the framework to two exemplary research processes in the field of bat ecology. One process represents basic research, investigating differences in airspace usage between bulldog bats *(Mops plicatus)* and tomb bats *(Taphozous theobaldi)*. The other exemplifies application-oriented research, examining whether greater mouse-eared bats *(Myotis myotis)* are more likely to fly in areas without artificial light compared to illuminated areas during their nocturnal flights. While these examples serve as an initial application, the framework is designed to be adaptable to virtually any scientific research process. By focusing on authentic content derived from actual research, the videos provide illustrative examples of complex scientific practices. Rather than emphasizing research findings alone, the framework priorities the description of scientific processes, thereby offering a bridge between scientific inquiry and classroom learning.

The framework draws on insights from science education, science and technology studies (STS), philosophy of science, and multimedia learning research. Science education has increasingly shifted toward competence-oriented approaches that emphasize the flexible application of knowledge in diverse contexts. STS and philosophy of science offer complementary perspectives by examining how scientific knowledge is socially, culturally, and philosophically constructed and situated (de Boer et al., 2021; Latour, 1987; Latour & Woolgar, 1986). These perspectives deepen our understanding of science as a dynamic and socially embedded endeavor.

Multimedia learning strategies play a critical role in enhancing the effectiveness of the framework. Grounded in cognitive theory, these strategies encompass the use of text, visuals, animations, and audio to support learning processes (Brame, 2016; Kulgemeyer, 2020; Mayer, 2009). They promote deeper engagement and comprehension by presenting content in dynamic and accessible formats that align with learners' cognitive capacities.

To develop a framework that authentically represents scientific inquiry in educational videos, this paper draws on three key disciplinary perspectives:

1. Science Education, which emphasizes the importance of students' understanding of the nature of science and the development of scientific reasoning skills.
2. Science Communication, which contributes strategies for making complex scientific processes accessible and engaging to diverse audiences.
3. Subject-Specific Didactics, which ensures that the representation of scientific content and practices aligns with disciplinary norms and supports curriculum-relevant learning goals.

By integrating these diverse disciplinary perspectives, this paper proposes a systematic framework for video development that not only communicates scientific findings but also foregrounds the practices through which these findings emerge. This approach encourages reflection on science as a process and supports students in developing a more authentic understanding of scientific inquiry. Ultimately, the framework aims to bridge the gap between students' personal perceptions of science (personal authenticity) and the realities of scientific practice (disciplinary authenticity) (Schriebl et al., 2023), thereby laying the groundwork for innovative and effective educational environments.

2.2 Theoretical Background

In cognitive psychology, scientific reasoning includes the abilities needed for scientific problem-solving and the reflection on this process at a meta-level (Krell & Hergert, 2019; Morris et al., 2012). The most common conceptualization of scientific reasoning describes it as a concept that includes eight independent sub-skills. These scientific reasoning skills are: problem identification, questioning, hypothesis generation, construction and redesign of artefacts, evidence generation, evidence evaluation, drawing conclusions, communicating and scrutinizing (Opitz et al., 2017). Current conceptualizations of scientific reasoning distinguish among several independent but coordinated skills which results from criticism of the traditional notion of *the scientific method* (Opitz et al., 2017). The criticism relates to the formulation of *the scientific method* in the singular, which contrasts with the variety of methods actually available and used in the various scientific disciplines (Kind & Osborne, 2017).

Since (actual) scientific research processes rarely follow a linear path, contemporary conceptualizations allow for flexibility, enabling individuals to switch between skills and practice multiple skills simultaneously, thereby providing a more authentic depiction of how scientists actually work (National Research Council, 2012). The individual scientific reasoning skills require not only content knowledge but also procedural and epistemic knowledge (Kampa & Köller, 2016; OECD, 2023b). Kind and Osborne (2017) emphasize the cultural argument in relation to the relevance of scientific reasoning and argue for a coherent account of the construct based on six styles of scientific reasoning, each of which contains ontic, procedural, and epistemic entities or constructs. For instance, in the context of experimentation, students need to understand not only "how to get reliable data [...] but also why reliability is important" (Kind & Osborne, 2017, p. 16).

The video development framework is designed to represent all six styles of scientific reasoning, thereby offering a multifaceted view of scientific inquiry. In particular, it aligns closely with the second style, *experimental evaluation*, which involves using empirical investigation to establish patterns, differentiate objects, and test predictions of hypothetical models (Kind & Osborne, 2017, p. 11). For example, a video might depict how researchers control variables in a bat flight experiment to ensure reliable data, while also explaining the epistemic rationale behind variable control, namely, to isolate causal relationships and justify claims.

Beyond experimentation, the framework also supports the third style, *model construction*, which is central to many scientific disciplines. Videos can visualize how scientists build explanatory models, such as ecological models of bat movement in urban landscapes, and how these models serve as tools for hypothesis generation and theory refinement (Nersessian, 2008). This not only illustrates procedural steps but also foregrounds the epistemic function of models in science.

By explicitly integrating epistemic knowledge into video narratives, the framework counters the oversimplified notion of a singular "scientific method" and instead reflects the ontological, methodological, and epistemic diversity of scientific practice (Cartwright, 1983; Hamilton, 2006; Schummer, 2006). This approach aligns with contemporary science education efforts to teach the nature of science (Lederman, 2007; National Research Council, 2012) and supports students in developing a deeper, more authentic understanding of how scientific knowledge is constructed and justified.

The concept of nature of science is internationally recognized as a crucial component of scientific literacy (Cofré et al., 2019; Dagher & Erduran, 2016). Accordingly, the integration of nature of science into science education is emphasized in numerous international curricula (Erduran & Dagher, 2014; McComas & Olson, 2002; Osborne et al., 2003). While there is broad agreement on its importance, interdisciplinary discussions about the theoretical foundations of nature of science are ongoing. A central point of departure in this discussion has been the *consensus view*, which identifies a set of nature of science aspects derived from the literature and serves as a basis for the development of assessment instruments (Lederman et al., 2002; Lederman & Abell, 2014). Although the *consensus view* has inspired a substantial body of empirical research, it has also faced criticism for its limitations, promoting the development of alternative conceptual frameworks. These include:

i.) the *whole science* framework (Allchin, 2011),

ii.) the *family resemblance approach* (Dagher & Erduran, 2016; Erduran & Dagher, 2014; Irzik & Nola, 2011, 2023), and

iii.) the *semantic view of scientific models* (Adúriz-Bravo, 2013b, 2013a).

The *whole science* framework "entails reframing current nature of science characterizations from selective lists of tenets to the multiple dimensions shaping reliability in scientific practice, from the experimental to the social, namely, to Whole Science" (Allchin, 2011, p. 518). Taking a more holistic view, Allchin (2011) proposes the use of cases from contemporary news and history to establish contextualized assessments instruments. The *family resemblance approach* similarly advocates for a broader conception of nature of science, defining science as a cognitive-epistemic and social-institutional system. Within this framework, scientific disciplines are metaphorically portrayed as family members, similar, yet distinct. The *semantic view of scientific models*, rooted in contemporary philosophy of science, employs narrative texts in the form of short stories to facilitate philosophical discussions of nature of science with science teachers (Adúriz-Bravo, 2013b, 2013a).

From a methodological perspective, the *consensus view* and the *family resemblance approach* can be categorized as primarily *deductive*, as they define nature of science aspects based on theoretical constructs. In contrast, the *whole science* framework and the *semantic view* adopt more *inductive*, case-based approach, constructing situated nature of science understandings through contextual examples. A combination of these inductive and deductive approaches is considered promising for science education research (Krüger et al., 2018).

This paper builds on this desideratum by integrating both perspectives: it incorporates the case-based orientation of the *whole science* and *semantic view* approaches through the use of authentic research process cases, while grounding the foundational structure of the video development framework in the literature-based theoretical constructs of the *consensus view* and the *family resemblance approach*.

2.2.1 Authentic Science in Science Class – Both Goal and Black Box?

For several decades, educational policy organizations and international standards have highlighted the importance of student engagement in the scientific practices and thought processes of scientists to enhance learning (Furtak et al., 2012). The US *Next Generation Science Standards* identify science practices as one of three dimensions of science learning, aiming to describe what scientists do and explain what is meant by inquiry in science (NGSS Lead States, 2013). Learning environments that address scientific practices and thought processes of scientists are often referred to as *authentic* (Stamer et al., 2020). Given the increasing frequency and broad application of the term, Schriebl et al. (2023) developed a model of authenticity in science education that distinguishes between *real-world authenticity*, *disciplinary authenticity*, and *personal authenticity*. Real-world and disciplinary authenticity represent external perspectives, such as those of science education researchers, while personal authenticity refers to students' perceived authenticity as they engage in the learning environment. Science education literature most often uses the term *authentic* in the sense of disciplinary authenticity, referring to the practices of professional scientists (Anker-Hansen & Andreé, 2019).

In response to these challenges, Allchin et al. (2014) identified three basic approaches to nature of science instruction, student inquiry, historical cases, and contemporary cases, each with distinct strengths and limitations. Such inquiry, on the one hand, "develops experimental competences: framing hypotheses, designing investigations, handling data, evaluating results", but on the other hand, "may be viewed as artificial exercise or school 'game', not as genuine science". Historical cases, "when framed in inquiry mode, can develop scientific thinking skills – more efficiently than with hands-on inquiry", but "may seem 'old' and irrelevant" and do "not support understanding of 'science-in-the-making'" (Allchin et al., 2014, p. 473).

Contemporary cases, which represent still unsolved scientific cases from the news, help "motivate engagement through authenticity and 'here-now' relevance", but "cannot be fully resolved, leaving uncertainty and incomplete nature of science lessons" and "cannot exhibit details of processes which are not yet public or are culturally obscured" (Allchin et al., 2014, p. 473).

These approaches differ in their potential to convey authentic scientific reasoning. Student inquiry fosters procedural competencies but may lack epistemic depth. Historical cases can support scientific thinking but often fail to represent *science-in-the-making*. Contemporary cases offer relevance and engagement but are limited by the constraints of science communication and unresolved processes.

Teacher educators consider learning strategies that involve students using methods based on the work of scientists to understand scientific concepts, processes, and nature of science to be important and valuable in promoting student learning, engagement, curiosity, and motivation. However, these inquiry-based learning strategies are often given less priority in daily routines than the teacher educators would desire (Strat et al., 2024). In science class, inquiry-based learning environments are often pre-structured in a manner that allows only one method of thinking and working. The science education literature uses a *cookbook* as a metaphor to describe how students perform scientific inquiry tasks similar to following a recipe from a cookbook ("cookbook-style"; (Heering & Höttecke, 2014; Kang & Wallace, 2005). The cookbook answers 'what' questions (content knowledge), such as '3 eggs'. However, it does not address 'why' questions (epistemic knowledge), such as 'why are eggs important for the quality of a cake batter'.

Yet, the generation of scientific knowledge comprises a variety of scientists' thought processes, such as decisions about methods, because it is "of a contingent and open-ended nature" (Clough, 2006; Ruhrig & Höttecke, 2015, p. 448). Therefore, *cookbook-style* student inquiry does not represent authentic scientific practices due to pre-structuring and does not present a coherent account of scientific reasoning that comprises content knowledge, procedural knowledge, and epistemic knowledge (Kind & Osborne, 2017).

The authentic, *science-in-the-making* presentation of science has long been a topic in science communication. As early as the 1960s, Sir Peter Medawar reflected on the nature and purpose of scientific papers (Medawar, 1996). He argued that their formal structure does not accurately reflect scientists' actual thought process during research. Similarly, Lawson (2000) described how scientific writing often renders the hypothetico-deductive reasoning processes invisible.

While this structure enhances communicative clarity, it simultaneously risks obscuring the epistemic deliberations that are inherent to authentic scientific inquiry. In this sense, scientific papers typically present a canonized, well-structured, and *post hoc* reconstruction of the research process – representing *ready-made science* – whereas the genuine cognitive and procedural dynamics of scientific work often remain hidden from the reader.

Latour and Woolgar (2013) refer to the way in which scientific and technical work is made invisible as *Black Boxing*. In this metaphor, the research process itself represents a *Black Box*, focusing only on the input and output of the research process. Due to the success of the process and the credibility of the outputs, there is no need to unpack the internal complexity of the Black Box. They further argue that "the activity of creating Black Boxes, of rendering items of knowledge distinct from the circumstances of their creation, is precisely what occupies scientists the majority of the time" (p. 259).

In science education, this metaphor applies to teaching approaches that present finalized results without revealing the reasoning and decision-making processes behind them. Previous approaches in science education, such as the use of original research articles in high-schools (Ariely & Yarden, 2025; Yarden et al., 2001), aim to address authentic scientific research processes in the classroom. However, these approaches often present a *post hoc* reconstruction *of ready-made science*, similar to how scientific papers communicate findings.

Overall, while disciplinary authenticity is a widely endorsed goal in science education, current teaching approaches often fall short of making the research process visible to students. Authentic cases used in classrooms frequently remain black-boxed, either due to design limitations or the conventions of science communication, which favor *ready-made science* over *science-in-the-making* (de Boer et al., 2021; Latour, 1987).

2.2.2 Using Videos to Make the Work and Thinking of Scientists Visible to Students

Videos have become a main tool for science communication and are also considered effective for teaching (Berk, 2009; T. Jones & Cuthrell, 2011) and teacher education (Criswell et al., 2022; Forsythe et al., 2022). Besides the positive effects of using different technologies in school (Means et al., 2009; Schmid et al., 2014), meta-analyses have demonstrated that especially videos have the potential to enhance learning (for an overview, Brame, 2016). Research also shows, however, that the medium of video is not effective per se (Guo et al., 2014) but should follow empirically validated design principles. The theoretical basis is the *Cognitive Theory of Multimedia Learning* (Mayer, 2009). Numerous empirical studies have identified aspects of multimedia learning that help or hinder students' learning (Kulgemeyer, 2020). The multimedia principle and the modality principle play a central role regarding videos (Mayer, 2009). The multimedia principle acknowledges two channels for information, the visual and the auditory channel, which are independent and have limited capacities. The modality principle states the combination of pictures and auditory information is more effective than a combination of pictures and written information. Videos fulfill both criteria and, therefore, a combination of visual and auditory information qualifies as beneficial for learning.

Videos used in science education vary in terms of their creators, such as by researchers for the purpose of science communication and outreach, by science educators for teaching purposes, by amateur or professional developers as explanatory tools for scientific contexts, and by teachers or students themselves (Seethaler et al., 2020). They also differ in terms of their objectives, the degree of didactic structuring, the degree of details they provide regarding scientific research processes, and the manner of communication (Boy et al., 2020). Explanation videos have recently been extensively researched (Brame, 2016; Kulgemeyer & Geelan, 2024). Videos produced following the framework of effective science explanation videos (Kulgemeyer, 2020) are highly structured and designed to foster student skills. The focus of this type of video is on the content (specific topics, methods, or concepts), not on an authentic representation of the research process or the scientists' thought processes.

In addition to promoting students' conceptual understanding and knowledge generation, that is, focus on the scientific contents, videos have the potential to foster an understanding of the processes of science, that is, "seeing how science works", as well as the epistemic foundation of scientific research processes (Evagorou et al., 2015, p. 1). Science education research that aimed to provide students with an authentic picture of science and to counter stereotypes of scientists, developed videos that focus on scientists' activities (Stamer et al., 2020). These short videos are designed to capture typical scientific activities, thereby addressing students' interest in and perception of authentic science. By focusing on individual scientific activities rather than the entire scientific research process, the video vignettes aim to engage students by providing concentrated insights into specific aspects of scientific work. These videos are neither designed to focus on student skills nor to systematically include a differentiation of the manner of communication in the context of *science-in-the-making* or *post hoc* reconstructions of *ready-made science* within the research process. However, existing approaches do not yet fully realize the potential to show details of the research processes and thought processes, often black boxed.

In this paper, we argue that videos as a tool have the potential to make the way scientists work and think visible and thus tangible to students. We further argue that the integration of addressing student skills and providing insights into authentic research processes is particularly valuable. Therefore, we demonstrate a systematic video development framework that builds on educational standards regarding scientific practices, systematically considers scientific reasoning skills and nature of science understanding, and provides insights into authentic scientific research processes on open research questions. The last aspect is particularly important, because – unlike videos that are produced after the scientific study has already been conducted – videos that are produced synchronously with the actual research process, allow for an authentic presentation in the sense of science-in-the-making.

2.3 The Systematic Video Development Framework

We systematically developed the framework based on literature on scientific reasoning, nature of science, authenticity, multimedia learning, and philosophy of science. The framework distinguishes between three structural levels, ranging from a wide perspective (macro) to a medium (meso) and a fine-grained level (micro) (Figure 1):

1. The macro level: The foundational structure of the videos based on scientific reasoning and nature of science literature that comprises the chapter structure according to scientific reasoning skills as well as nature of science categories.
2. The meso level: An authentic scientific research process (including all its scientific practices, uncertainties, unpredictabilities; based on authenticity literature).
3. The micro level: Specific video building blocks for ways to present scientific practices (*cookbook-style* vs. *scientific reasoning style*) and scientists' thought processes (*science-in-the-making* vs. *ready-made science*; based on literature on scientific reasoning, authenticity, multimedia learning, and philosophy of science).

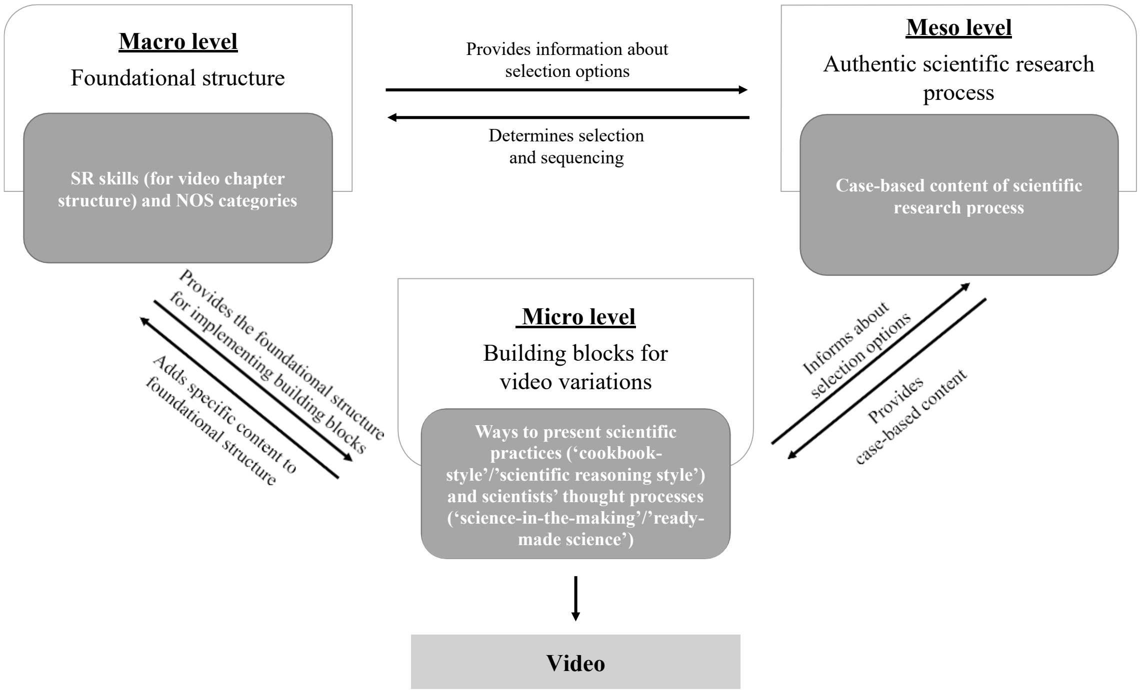

Figure 1

Video Development Framework on Macro, Meso and Micro Level

The structure of the framework combines, on the one hand, theoretically derived aspects that are essential for selecting and sequencing information during video development to systematically address student skills and, on the other hand, a flexible structure with the potential to present every scientific research process in a video. Through the clearly defined building blocks and the flexibility regarding the authentic scientific research processes, it enables insights into scientists' work and their thought processes. The various options available at the micro level lead to different video variations. For example, when deciding how to present scientific practices in the video, it is possible to choose between either the *cookbook-style* or the coherent account in the sense of a *scientific reasoning style*. In the video development process, the selection and sequencing of content on macro and meso levels are determined by the authentic scientific research process. In contrast, decisions with regard to science education determine the choice of building blocks at the micro level.

2.3.1 Macro Level: The Foundational Structure

The macro level, which comprises scientific reasoning skills and nature of science categories, provides a foundational structure for the videos, because providing a structure is a criterion for effective science explanation videos (Kulgemeyer, 2020). The macro level provides information about options for selecting scientific reasoning skills and nature of science categories (whether or not they are selected is determined by the authentic research process, see the following chapter on the meso level).

The scientific reasoning skills are used to derive a video chapter structure. Possible video chapters are, for example, problem identification, questioning, hypothesis formulation, planning of scientific investigation, carrying out scientific investigation, data analysis, data interpretation, drawing conclusions, and communication and reflection (Opitz et al., 2017; Pedaste et al., 2015). The macro level of the framework allows the structure of the video chapters to be chosen depending on the course of the authentic scientific research process, which may include, for example, back-and-forth navigation or loops within the research process. This flexibility in the foundational structure of the videos is essential because the scientific practices of authentic scientific research processes are closely interlinked and not strictly linear (Osborne, 2013).

A central idea of the framework involves accompanying authentic research processes, so that the videos show work on open research questions. At the beginning of the videos, the scientists themselves do not know the answers to their research questions, nor do they know whether, despite careful planning, unforeseen circumstances will arise during the research process. Therefore, it is impossible to have a pre-determined structure of video chapters for the entire research process. The video chapter structure has to be adaptable to accurately reflect what happens during the research process, such as revisiting hypotheses or conducting additional data collection. Adjustments in the sequencing of the chapters are also necessary if, for example, the exemplary scientific research process is not hypothesis-testing (Kind & Osborne, 2017).

The nature of science categories are derived from the science education literature and serve as secondary building blocks of the foundational video structure. They draw on established nature of science frameworks, such as the family resemblance approach, and on review articles (Cofré et al., 2019) Typical nature of science categories include tentativeness, observation and inference, subjectivity, creativity and imagination, the empirical basis of knowledge, the social and cultural embeddedness of science, the relation between theory and law, the scientific method, and collaborative interaction.

The placement of these categories within the video chapters is both fixed and flexible. Some categories need to be aligned with a specific video chapter. This follows the ScieNO-framework (Reith & Nehring, 2020), which links scientific reasoning skills with views on the nature of scientific inquiry. For example, reflecting on the subjectivity of interpretations is part of the video chapter on data interpretation and should always be included there. Other categories, such as teamwork in scientific research processes, are not tied to a specific chapter. These can be addressed in whichever video they best fit, depending on the respective research process. The aim is not to cover every possible nature of science category in every video. Rather, science educators who accompany the scientists during the research process select categories that are particularly relevant, in order to provide precise insights into authentic scientific practices and thought processes and thereby promote students' understanding of nature of science.

2.3.2 Meso Level: Authentic Cases of Scientific Research Processes

The meso level represents the case-based content. This is the core of the video development framework and stems from an authentic and current research process that is presented as an example. The meso level includes all information in the video that is not at the level of scientific research in general but relates specifically to the exemplary research process, for example, the research question and hypothesis addressed in the video, the specific methods used, and the data evaluation are all considered case-based content. An explanation of why it is important for scientific research processes in general to formulate a research question, for example, does not represent case-based content, but content on the micro level (see micro level section).

Each video presents a scientific research process that is followed throughout its entire course (i.e., throughout all scientific practices). While the macro level provides literature-based options for video chapters (derived from scientific reasoning skills), the meso level determines the selection and sequencing of the video chapters based on the actual course of the scientific research process. For example, if the researchers need to revise hypotheses or collect additional data during the research process, this will directly affect the structure of the video chapters. The videos show the scientists in the working environment of the research process. In addition, the scientists describe and explain in interview scenes what they do during each individual scientific practice. The interview scenes are particularly important for presenting the scientists' thought processes during the research process which allows for the presentation of *science-in-the-making* (de Boer et al., 2021; Latour, 1987).

2.3.3 Micro Level: Building Blocks for Video Variations

The micro level provides different ways to present scientific practices (*cookbook-style* vs. *scientific reasoning style*) and scientists' thought processes (*science-in-the-making* vs. *ready-made science*; see Figure 1). Importantly, this building-block-structure on the micro level allows creating different variations of videos, depending on the combination of specific blocks of information. Thereby, the systematic video development framework provides the ultimate possibility to create different video variations with the same case-based content and the same information on the scientific process. In other words, the information on the macro level and meso level would be identical in the video variations and the differentiation between the video variations would exclusively originate from the micro level.

The micro-level building blocks described in this paper are examples of those that were varied in the VideT project to empirically test the effects. Other micro-level building blocks could also be integrated into the framework. In the VideT project, we used the following building blocks:

1. Presentation of scientific practices either in a *cookbook-style* or as a coherent account in the sense of *scientific reasoning style*,
2. Presentation of scientists' thought processes either as *science-in-the-making* or as *ready-made science*.

In the following section, we will explain these building blocks in detail and provide examples of video scripts from the VideT project, in which we accompanied two exemplary research processes throughout their entire course.

2.3.3.1 Presentation of Scientific Practices on the Micro Level

The video building blocks to present scientific practices in a *cookbook-style* (Clough, 2006; Kang & Wallace, 2005; Ruhrig & Höttecke, 2015) provide knowledge on 'what' questions regarding the addressed scientific reasoning skills of the exemplary research processes, but knowledge about the 'how' and 'why' of scientific processes from a general sciences perspective remains a *Black Box* (Latour & Woolgar, 2013).

In contrast, the presentation as a coherent account in the sense of *scientific reasoning style* (Kind & Osborne, 2017) adds knowledge from a general perspective of scientific processes, addressing both the *how* and the *why*; that is, procedural and epistemic knowledge. The resulting video variation in the style of scientific reasoning also includes the case-based content concerning the *what*, which remains identical across the *cookbook-*

style and *scientific reasoning style*. However, the procedural and epistemic knowledge is added to depict a coherent account, following the framework proposed by Kind and Osborne (2017). For example, the video explains why the formulation of a hypothesis is essential for scientific inquiry (Table 1). While this addition results in a slightly longer video, the difference in duration was considered negligible and is not expected to have influenced student motivation or engagement.

Table 1

Exemplary Video Transcript - Scientific Practices

Presentation of scientific practices	**Exemplary video transcript** **(Name of the scientist in this study: Daniel)**
Cookbook-style	In Daniel's case, it [sc. the hypothesis] reads: Bulldog bats use the airspace at high altitudes more than tomb bats.
Scientific reasoning style	A hypothesis is an assumption based on the current state of knowledge. Like the research question, it must be formulated objectively and precisely. In Daniel's case, it reads: Bulldog bats use the airspace at high altitudes more than tomb bats. Formulating a hypothesis is always an important step, because it permeates the research process like a "common thread". It influences the planning and execution of the study. In the end, the results are also related to the hypothesis.

Note. Transcript excerpts illustrating scientific practices in either a *cookbook-style* or a *scientific reasoning style*, taken from the "Formulating Hypotheses" chapter of a study on bat airspace use.

Table 1 presents an exemplary transcript from the chapter *formulating hypotheses* of the exemplary scientific study on the differences in the use of airspace between the bulldog bat and the tomb bat. The presentation in a *cookbook-style* names the hypothesis of the exemplary research process, but no procedural or epistemic knowledge is added as an explanation for the existence of the hypothesis. In contrast, the coherent account in the sense of *scientific reasoning style* names the hypothesis of the research process and adds procedural and epistemic knowledge (see Table 1).

2.3.3.2 Presentation of Scientists' Thought Processes on the Micro Level

The video building blocks for ways to present scientists' thought processes do not address the level of individual scientific reasoning skills, but rather, open a *Black Box* on a second level, the level of the scientists' minds. This includes thought processes and decisions during the research process. Table 2 shows an exemplary transcript from the chapter *Planning an Investigation* of the exemplary scientific study on the differences in the use of airspace between bulldog bats and tomb bats.

The presentation of scientists' thought processes as '*science-in-the-making'* is based on literature regarding authenticity in science education (Schriebl et al., 2023) and aims to demonstrate thought processes in the videos as they actually take place in scientists' minds during scientific research processes (similar to think aloud; de Boer et al., 2021; Latour, 1987). The thought processes addressed in the videos include, for example, sample size trade-offs, dealing with unexpected values, selection of materials, and reflections regarding nature of science aspects, for example, tentativeness of research findings, uncertainty, or the subjectivity of interpretation. In the *science-in-the-making* video variation, the thought processes are verbalized by the scientists, starting with the aspects the scientist must consider prior to making a decision (e.g., in the case of sample size trade-offs in bat ecology, the scientists have to consider animal welfare, the budget, and methodological issues to determine the sample size). After presenting these deliberations, a well-thought-out decision is communicated in the *science-in-the-making* video variation.

In contrast, the *ready-made science* video variation is based on literature describing the communication in scientific papers as depicting a *post hoc* reconstruction of *ready-made science* within the research process (Ruhrig & Höttecke, 2015). The *ready-made science* video variation addresses the same topics as the *science-in-the-making* video variation (e.g., sample size trade-offs, dealing with unexpected values, selection of materials, reflections regarding nature of science aspects), but the communication is structured differently. Instead of the scientists' thought processes themselves, well-thought-out decisions are communicated in two steps: 1.) the decision and 2.) a justification of the decision. This leads to the situation that the *ready-made science* video variation black boxes the actual thought processes while the focus is on the output of the thought process (Latour & Woolgar, 2013). It is important to note that there is no difference in the representation of the scientist's expertise between the video variations. Rather, the video variations represent the same research process, the same thought processes, the same level of expertise, and the same scientists as protagonists in both *science-in-the-making* and *ready-made science*. The only difference is the way of communicating the thought processes.

Table 2

Exemplary Video Transcript – Scientists' Thought Processes

Presentation of scientists' thought processes	Example from video script (Name of the scientist in this study: Daniel)
Science-in-the-making	Daniel considers which loggers to choose: "Of course, there is always a trade-off between what you would like to achieve, what data you would like to generate and what is possible. For our case, we would like to generate data and find out where the animals are hunting. In other words, we would prefer to use GPS and record for many, many days, but that is simply not possible because the animals still have to carry these loggers. The loggers themselves don't weigh that much. They have miniature transmitters on them, sensors that are often used in cell phones or similar, but the batteries that these loggers need are relatively heavy. In other words, we really work with miniature batteries that provide just enough battery life for the sensors, but which the animals can still carry." Based on these considerations, Daniel selects loggers that measure temperature and air pressure. He can then calculate the flight altitude from these values.
Ready-made science	Daniel opts for loggers that measure temperature and air pressure. He can then calculate the altitude from these values. GPS loggers, which can record data for many days, require powerful batteries. They are too heavy for the small bats. "When selecting a logger, we have to pay attention to various aspects. These include the sensors, above all the weight, the size, of course, and the way in which we can then access the data again."

Note. Exemplary video script to present scientists' thought processes either as *science-in-the-making* or as *ready-made science* from a sample-size decision scene from chapter "Planning an investigation" of scientific study on the use of airspace of bulldog bat and tomb bat.

Table 2 shows an exemplary transcript illustrating how scientists' thought processes are presented in the two video variations. The presentation of scientists' thought processes as *science-in-the-making* aims to follow the course of the actual scientists' deliberations. It begins with the aspects the scientist must consider and concludes with the well-thought-out decision. In the *ready-made science* video variation, the communication process is reversed (in a chiastic structure): it starts with the well-thought-out decision and ends with a justification of the decision. In this shorter variation, some content was supplemented with illustrative images to preserve comprehension while maintaining comparable duration across conditions. The communication structure of the *ready-made science* variation is based on the style of scientific papers (Lawson, 2000; Medawar, 1996).

2.4 How Does the Video Development Framework Advance Research in Science Education? Discussion and Implications for Research

A major strength of the video development framework is the potential to make scientists' working and thinking visible for students while systematically addressing student skills. The presentation of how scientists work (according to a systematic chapter structure based on scientific reasoning skills) and how they think during the research process regarding aspects of nature of science (e.g., uncertainty, tentativeness, subjectivity of interpretation, decision processes regarding sample-sizes) are theoretically derived and designed to open the *Black Box* of scientific research processes (Latour & Woolgar, 2013).

Current science education literature addresses *Black Boxes* in particular in the context of modeling and mechanistic reasoning. Recent research acknowledges explanatory black boxes as an inherent part of mechanistic explanations and argues for explicit discussions of explanatory black boxes, taking into account possible effects "on learning, understanding and reasoning about mechanisms" (Haskel-Ittah, 2023, p. 5). In the context of modeling, the term *Black Box* describes an activity in which students work with an invisible internal system (literally a *Black Box*) to foster their understanding of modeling and nature of science (Krell & Hergert, 2019; Krell & Krüger, 2016).

In both cases, the focus and the learning objectives differ from our approach, which centers on thinking and working in authentic scientific research processes. The video development framework, therefore, contributes to science education literature with regard to addressing (authentic) scientific research processes. The claim that science educators should consider the effects of black boxes on learning and reasoning (Haskel-Ittah, 2023) is also relevant here.

Research Potential of the Framework. In this paper, we argue that videos based on the proposed framework are potentially promising for research in science education – for example, by testing their effects on variables such as students' scientific reasoning skills, views of the nature of science and the nature of scientific inquiry, epistemic beliefs, perceptions of authenticity, and motivation. This applies in particular to the different video variations that follow from the framework's micro level.

A second major strength of the framework is the possibility to create different video variations. For example, the systematic variation (according to a 2 x 2 design) of the micro level building blocks described in Figure 1 (*cookbook-style* vs. *scientific reasoning style* with regard to scientific practices; *science-in-the-making* vs. *ready-made science* with regard to scientists' thought processes) leads to four video variations.

The conception of the framework follows Kind's and Osborne's (2017) argumentation for a coherent conceptual schema of scientific reasoning, addressing previous approaches that neglected procedural and epistemic knowledge. The framework allows for a systematic integration of procedural and epistemic knowledge for each scientific reasoning skill.

In terms of how scientists communicate their thought processes, the framework allows for developing videos that present reasoning either as a *post hoc* reconstruction of *ready-made science* – based on the communicative style of scientific papers – or as concurrent think-aloud in the sense of *science-in-the-making*.

The integration of the video variations implies two benefits for research:

First, they allow for empirical testing and the identification of effects on cognitive and affective variables. In the case of scientific reasoning, the framework offers a coherent account that includes procedural and epistemic knowledge. Second, the variation in the representation of scientists' thought processes is grounded in science education literature and educational standards that emphasize the importance of providing authentic insights into *science-in-the-making*.

As an innovative element, it remains an open research question whether and to what extent the video variations influence cognitive and affective variables differently.

Implications for Science Communication. The contrasting video variations can also be used as a reflection tool. For example, the could support reflection on how science communication represents science and how it is perceived. Current audio-visual science communication tends to emphasize results while neglecting research processes and nature of science.

However, in times of social media and science misinformation, nature of science communication becomes increasingly important (Allchin, 2011, p. 202; Höttecke & Allchin, 2020). The systematic video development framework offers potential for research on science communication, as it could enhance the understanding of nature of science – including aspects like uncertainty – and improve the ability to recognize misinformation.

The development of the structural levels of the framework builds on the desideratum for combining deductive and inductive approaches in the context of nature of science (Krüger et al., 2018). The foundational structure (macro level) is derived from the scientific reasoning and nature of science literature and represents the deductive approach (as used by the *consensus view* and the *family resemblance approach)*. The authentic case of a scientific research process (meso level) represents the inductive approach (as used by the *whole science approach* and the *semantic view*). Further research should empirically test the effects of this theoretical contribution to science education.

2.5 How do Science Lessons Benefit from the Video Development Framework? Educational Implications

Teaching scientific practices in a way that allows students to understand the actual working and thought process of scientists is a key curricular goal. The combination of a skill-oriented approach and the use of authentic research processes is a major strength of the systematic video development framework and benefits science teaching. Studies have shown that direct contact to scientists can lead to an authentic perception of science (Braund & Reiss, 2006; Pea, 1994). As authentic research processes can hardly take place at school, we argue that videos are valuable tools for bringing authentic research processes to the class (Brame, 2016; Goldman et al., 1994, 1996). The approach presented in this paper has the advantage that teachers can simultaneously provide insights into authentic research processes in the class and use didactically structured materials that address the skills defined in the educational standards.

Notably, this approach is not intended to replace existing instructional approaches, but rather to supplement them. The combination of different approaches could balance the strengths and weaknesses of the individual approaches and coherently cover the various aspects of scientific inquiry competences in the class. For example, regarding the strengths and weaknesses of the three basic approaches to nature of science instruction (i.e., student inquiry, historical cases, contemporary cases; Allchin et al., 2014), the advantages of *student inquiry* and *contemporary cases* described would also apply to the use of the videos, but in addition, the disadvantages would not apply due to the authenticity of the cases and the opportunity to gain insight into the research process. This indicates that the videos could represent a meaningful development in science education, enhancing traditional hands-on experiments by providing additional perspectives and supporting deeper engagement with scientific practices.

Teachers and science educators can utilize the systematic video development framework to analyze science videos in terms of the presentation of scientific practices and scientists' thought processes. This framework can serve as an analysis tool for any science video, whether it is developed for science communication or educational purposes. Using the framework as an analysis and reflection tool provides valuable insights into which scientific practices are addressed in the video and whether procedural and epistemic knowledge is presented. Based on the results of the analysis, teachers and science educators can decide which videos to use in educational settings, but also which aspects they have to explicitly discuss with students if these are not or not sufficiently addressed in the videos.

Additionally, the video development framework offers the opportunity to discuss the portrayal of scientists' thought processes in school-related material or science videos on video platforms with students, that is whether or not thought processes, decision processes, and reflections of uncertainty are black-boxed in the video and whether or not the video presents an authentic picture of science in the sense of actual working and thinking of scientists. The reflection on how scientists' thought processes are presented, taking into consideration the difference between the presentation as *science-in-the-making* and as *ready-made science* may lead to a more in-depth understanding of nature if science and more authentic students' mental representations of scientists' thinking and working.

The videos could similarly be used in teacher education to train a professional perspective and provide insights into authentic scientific research processes as part of their professional development. Literature on inquiry-based learning shows that pre-service teachers require training in inquiry-based teaching during teacher training to be able to apply this teaching strategy in their own classes. Therefore, it is proposed that inquiry-based science education should focus on both preservice teachers as learners and as future teachers (Strat et al., 2024).

2.6 Conclusion

This paper has demonstrated a systematic video development framework that combines orientation on student skills based on science education literature with authentic cases of scientific research processes. Key components of the video development framework are i.) the macro level, the foundational structure of the videos based on cognitive psychology and science education literature that comprises the chapter structure according to scientific reasoning skills as well as nature of science categories, ii.) the meso level, an authentic scientific research process (including all its scientific practices, uncertainties, unpredictabilities), and iii.) the micro level, specific building blocks for ways to present scientific practices (*cookbook-style* vs. *scientific reasoning style*) and scientists' thought processes (*science-in-the-making* vs. *ready-made science*).

The key achievements of the framework are the potential to make scientists' working and thinking visible for students while systematically addressing student skills and the micro-level of the framework which allows for systematic distinctions between video variations. The framework conceptually contributes to science education by integrating interdisciplinary perspectives from science education, philosophy of science, and multimedia learning to provide a foundation for innovative educational approaches regarding one of the major goals of science education, an understanding of how scientists work and think as part of scientific literacy.

Despite the demand for educational resources that integrate aspects of *science-in-the-making*, there is currently a shortage of available material. The framework addresses this gap by creating and connecting these types of resources within the theoretical realm. In doing so, it meets normative demands for a paradigm shift from viewing science education as the transmission of ready-made knowledge to understanding it as a dynamic, inquiry-driven process. The main implication of the systematic video development framework is that it allows for empirical testing of video variations to validate its impact on cognitive and affective learner outcomes and that it can serve as a reflection tool to analyze the presentation of scientific processes.

From Theoretical Framework to Empirical Examination

Chapter 2 established a systematic framework for developing research process presentations that integrate scientific reasoning skills with authentic research practices. This framework provided the conceptual and methodological foundation for testing how different representations of the scientific process influence perceptions of tentativeness and credibility.

Building on this foundation, Chapter 3, “Research Process Presentations in Science Education: Perceptions of Credibility and Tentativeness in Research Findings”, examines controlled experiments with university students. Using the Thailand bat ecology case, it systematically compares text-based and video-based presentations, manipulating both the depiction of scientific practices and the portrayal of the scientists’ thought processes. These experiments allow for the first empirical evaluation of how the framework influences audience perceptions in a controlled, online context, providing insights into the balance between transparency and credibility.

3. Research Process Presentations in Science Education: Perceptions of Credibility and Tentativeness in Research Findings

Statement of Contribution

Author	**Author Position**	**Scientific Ideas %**	**Data Generation %**	**Analysis & Interpretation %**	**Paper Writing**
Julia Cathérine Thomas	1	90	100	100	70
Katharina Düsing	2	-	-	-	2
Vanessa van den Bogaert	3	-	-	-	2
Hannah Greving	4	-	-	-	2
Till Bruckermann	5	-	-	-	2
Anke Schumann	6	-	-	-	2
Miriam Brandt	7	-	-	-	2
Daniel Lewanzik	8	-	-	-	2
Christian C. Voigt	9	-	-	-	2
Joachim Kimmerle	10	10	-	-	14
Title of Paper	The Role of Research Process Presentations in Science Education: Perceptions of Credibility and Tentativeness in Research Findings				
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Abstract

Laypeople often struggle to understand the provisional nature of scientific knowledge. While scientific knowledge may be widely accepted within the scientific community, it is continually subject to revision and further development as new studies are published. These characteristics of science, where findings build upon each other over time rather than being entirely replaced by new discoveries, are not always well understood by the public. This becomes particularly problematic when research process presentations that emphasize the evolving, provisional nature of scientific knowledge are perceived as less credible, reinforcing misconceptions about the integrity and nature of science. In two experimental online studies on science education ($n_1 = 99$; $n_2 = 184$), we examined how different representations of the scientific process affect perceptions of credibility and tentativeness using text- and video-based presentations in the context of bat ecology as an example. c Our findings indicate that, although scientific knowledge is perceived as provisional, the way it is communicated can influence its perceived credibility. In both studies, perceived tentativeness was negatively correlated with perceived credibility, highlighting a challenge in science communication: the need to convey the evolving nature of scientific knowledge without undermining trust in its reliability.
Keywords: social science, education, psychology, science communication, research process, scientific inquiry, scientific uncertainty, tentativeness, credibility, research findings

3.1 Introduction

In today's technology-driven society, public trust in science and the credibility of scientific findings are fundamental for addressing global challenges. Effective science communication should not only convey results but also promote an understanding of how these findings are generated and validated. A key component of this process is the provisional nature of scientific knowledge, which is often misinterpreted as a lack of credibility rather than a strength of the scientific process. Clarifying the evolving, evidence-based nature of science can enhance trust and confidence in research outcomes.

Central to this issue are two related but distinct concepts: tentativeness and uncertainty. Scientific tentativeness refers to the provisional status of scientific conclusions, acknowledging that they are based on the best available evidence but remain open to revision as new data emerge (Bromme & Goldman, 2014; R. A. Duschl, 1988; Richter et al., 2019). This aspect is inherent to the scientific process and reflects its self-correcting nature. In contrast, uncertainty refers to the degree of precision or confidence in scientific measurements, models, or predictions. While scientific uncertainty can often be quantified and reduced through mathematical approaches (van der Bles et al., 2019), tentativeness persists as an epistemic feature of scientific reasoning (Flemming et al., 2020; Sinatra & Chinn, 2012). Despite their distinct meanings, these concepts are frequently conflated in science communication, leading to misunderstandings about the credibility, integrity, and reliability of research findings (Fischhoff & Davis, 2014).

From a communication standpoint, scientists face a significant dilemma: emphasizing uncertainty or the tentative nature of their findings may be perceived as diminishing their credibility. Conversely, neglecting these aspects risks oversimplifying the scientific process and eroding public trust when findings inevitably evolve (Bromme & Goldman, 2014). This tension highlights the urgent need for science communication strategies that effectively convey the provisional nature of scientific knowledge while preserving trust and confidence in scientific outcomes.

Scientific uncertainty is an inherent feature of research and knowledge generation (Gustafson & Rice, 2019, 2020; van der Bles et al., 2020). However, it is frequently overlooked or inadequately communicated to the public (Maier et al., 2016). Effective communication of this uncertainty plays a pivotal role in fostering understanding and trust, making it a critical aspect of science communication (Gustafson & Rice, 2020; Simis, 2013). Nevertheless, the perception that uncertainty undermines credibility presents a significant challenge. Many researchers prefer to present their findings as definitive, fearing that emphasizing their provisional nature might be misconstrued as a sign of weakness or unreliability (Flemming et al., 2015; van der Bles et al., 2019). This reluctance exacerbates a broader misunderstanding of the iterative and self-correcting nature of scientific knowledge development.

A deeper public understanding of how scientific knowledge is generated is essential for accurately evaluating research results. While scientific results are often presented as definitive and conclusive, within the academic community they are typically regarded as provisional and subject to revision (Bromme & Goldman, 2014; R. A. Duschl, 1988; Flemming et al., 2015; Kimmerle et al., 2015). Tentativeness refers to the acknowledgement that scientific conclusions are based on current evidence and may change as new data emerge. Unfortunately, this aspect is rarely communicated effectively to non-specialist audiences, resulting in widespread misconceptions about the value, significance, and reliability of scientific evidence (Flemming et al., 2020).

Even when scientists accurately communicate the provisional nature of their findings, it is often misunderstood by lay audiences (Fischhoff & Davis, 2014). Individual perceptions and interpretive frameworks play a critical role in how such information is received and understood (Fischhoff & Davis, 2014). It is therefore imperative for the public to grasp the importance of uncertainty as a fundamental aspect of the scientific process (van der Bles et al., 2019).

Recognizing that scientific findings are inherently subject to change and gradual refinement is fundamental to understanding the nature of the scientific process. Despite this provisional nature, scientists are required to make well-justified decisions within these parameters, ensuring that their research methods and conclusions are both robust and credible. This balance underscores the responsibility of scientists to uphold consistency and rigor, particularly when addressing complex problems and engaging in deliberative processes (Maier et al., 2016).

A theoretical lens through which to examine this challenge is offered by process models of trust formation, such as those proposed by Mayer et al. (1995). These models highlight the dynamic interplay of competence, integrity, and benevolence as critical components in building trust (Hendriks et al., 2017). Within the realm of science communication, trust is shaped not only by the content's accuracy and methodological rigor but also by how information or uncertainty is framed and delivered (Simis, 2013). Presenting scientific findings as tentative, while transparently acknowledging uncertainties, can bolster perceptions of integrity and openness, thereby fostering trust even amidst evolving evidence.

To address these concerns, the present study explores how different communication styles influence perceptions of scientific reasoning, tentativeness, and uncertainty. Drawing on a framework that differentiates between portraying scientist’s thought processes as authentic – in the sense of *science-in-the-making* (de Boer et al., 2021), emphasizing the iterative and uncertain nature of science – and portraying them as canonized – in the sense of *ready-made science*, highlighting fixed and authoritative conclusions – we investigate how these approaches affect laypeople’s understanding and trust. By analyzing declarative, procedural, and epistemic dimensions of scientific knowledge, this research seeks to illuminate how the portrayal of scientists' thought processes as *science-in-the-making* or *ready-made science* can either strengthen or diminish public trust and confidence in science.

3.1.1 Scientific Inquiry and Communication: Bridging Uncertainty and Understanding

To grasp the inherent uncertainty and tentativeness of scientific findings, it is crucial to first understand the scientific process itself. Rather than being a static or linear endeavor, this process is characterized by a dynamic interplay of hypothesis generation, experimentation, and the iterative refinement of theories considering new evidence. The scientific method – anchored in principles of inductive and deductive reasoning as well as the systematic falsification of hypotheses – provides a structured framework for navigating and productively engaging with uncertainty (Kind & Osborne, 2017).

Stakeholders who rely on scientific insights, including policymakers, educators, and the public, often face challenges in interpreting scientific evidence without a foundational understanding of these processes. Decision-makers, for instance, must assess whether research adheres to rigorous methodological standards and whether its conclusions are substantiated by reliable evidence. Similarly, innovators and practitioners seeking to translate research into practical applications require a nuanced comprehension of the processes that underpin discovery and progress (Fischhoff & Davis, 2014).

By addressing these uncertainties explicitly, science communication and science education can foster broader engagement with scientific topics, enabling diverse audiences to appreciate the iterative nature of scientific inquiry. Such an approach promotes critical thinking and informed decision-making, empowering stakeholders to evaluate scientific evidence more effectively and to participate in discussions about its implications with greater confidence.

3.1.2 Scientific Literacy as a Foundation

Scientific inquiry operates within two interconnected problem spaces: the hypothesis space and the experimental space, as described by the Scientific Discovery as Dual-Search (SDDS) model (Klahr & Dunbar, 1988). Originally developed to model scientific reasoning in the context of natural sciences, the SDDS framework emphasizes the iterative nature of inquiry, encompassing both the generation of plausible explanations and the systematic design of experiments to test them. While its roots lie in the cognitive modeling of natural science practices, its dual-space structure offers valuable insights into reasoning processes that are broadly relevant for fostering scientific literacy across disciplines.

Scientific inquiry draws upon a variety of reasoning methods, each contributing to the acquisition of knowledge and the derivation of conclusions from empirical data. Key reasoning processes include inductive reasoning, where general principles are inferred from specific observations; deductive reasoning, which applies general principles to specific cases; and the falsification of hypotheses, a cornerstone of scientific methodology (Kind & Osborne, 2017). Although traditional models, such as Chalmers' (2007) portrayal of the scientific method, present a structured, step-by-step approach, such frameworks have been criticized for oversimplifying the inherently dynamic and flexible nature of scientific practice.

In reality, scientific inquiry is a fluid and context-dependent process that incorporates diverse reasoning styles. These styles integrate declarative knowledge (factual content), procedural knowledge (the methodologies employed), and epistemic knowledge (the values and assumptions underpinning scientific practices). Together, these dimensions facilitate the iterative refinement and testing of scientific knowledge, ensuring its evolution in response to new evidence (Kind & Osborne, 2017).

Understanding the mechanisms of scientific inquiry is essential not only for scientists but also for the public (Flemming et al., 2015). Enhanced scientific literacy enables individuals to critically evaluate information, discern credible sources, and make informed decisions on science-related issues. However, despite its importance, formal education often neglects the dynamic and uncertain nature of the scientific process. Science curricula frequently prioritize established findings over the processes through which those findings were discovered, missing a critical opportunity to cultivate critical thinking and scientific literacy (Lederman et al., 2002, 2013; Valladares, 2021).

By addressing the iterative and evolving nature of scientific inquiry, education can help students move beyond perceiving science as a static body of facts. Instead, students can come to appreciate the provisional and evidence-driven nature of scientific knowledge, equipping them to navigate complex, real-world issues (Feinkohl et al., 2016). Empowering learners with this perspective not only fosters critical engagement but also prepares them to develop evidence-based solutions in an increasingly complex and scientifically informed society. A more critical engagement can thereby enhance comprehension and trust (Peffer & Ramezani, 2019; Windschitl et al., 2008).

This educational gap becomes even more problematic when scientific uncertainties are communicated to the public. Research has shown that presenting findings as tentative can sometimes reduce public trust in science, as perceived tentativeness may appear contradictory to credibility (Flemming et al., 2015, 2020; Hendriks et al., 2016b). However, these effects are often mediated by the public's familiarity with the iterative and uncertain nature of scientific inquiry. A shift from factual knowledge toward epistemic understanding – how knowledge is constructed, tested, and refined–may mitigate these challenges (Kind & Osborne, 2017).

Communicating scientific uncertainty effectively requires a transparent portrayal of the evolving nature of research and the role of evidence in shaping conclusions. By framing uncertainty as an integral and valuable aspect of scientific work, communicators can foster a deeper, more nuanced public understanding of science. This approach enhances credibility and trust while highlighting the interconnected dimensions of scientific reasoning, methodology, and epistemology.

3.1.3 Research Objectives and Design

The research presented here investigates how different communication styles and media formats influence people's perceptions of scientific processes, the credibility of research, and the inherent tentativeness of research findings. The primary aim is to enhance scientific literacy by identifying effective strategies for communicating complex scientific concepts and fostering trust in scientific research.

Previous research has shown that the presentation of scientific information significantly shapes public perception (Ophir & Jamieson, 2021). Studies on scientific literacy emphasize the importance of promoting deeper, more critical engagement with scientific information to improve both understanding and trust (Peffer & Ramezani, 2019; Windschitl et al., 2008). Grounded in the framework proposed by Kind and Osborne (2017), which categorizes scientific reasoning into *declarative*, *procedural*, and *epistemic* dimensions, this research examines how these elements influence comprehension and trust. Specifically, it explores the impact of two key factors: (1) the presentation of scientific practices (*cookbook-style* vs. *scientific reasoning style*), and (2) the portrayal of scientists' thought processes (*science-in-the-making* vs. *ready-made science*).

To provide context for scientific practices, detailed explanations link the "what" of scientific activities with the "why" and "how." This approach draws on Kind and Osborne's (2017) distinction of six styles of scientific reasoning, which encompass:

- *Declarative knowledge*: factual content and scientific concepts,
- *Procedural knowledge*: methods used to generate and validate knowledge,
- *Epistemic knowledge*: values and assumptions underlying scientific practices.

By systematically incorporating these dimensions, we aim to foster a comprehensive understanding of scientific reasoning and its contextual application.

Theoretical models such as *Elaboration Theory* (Reigeluth, 1999) suggest that explanations deepen understanding by helping people integrate new information with prior knowledge. In contrast, *Cognitive Load Theory* (Sweller, 1988; Sweller et al., 2011) highlights the challenges of overly detailed content, particularly for individuals with limited prior knowledge. These theories imply that while detailed explanations can enhance comprehension for audiences with sufficient prior knowledge, simplified content may be more effective for those less familiar with scientific concepts, an important consideration for interpreting the study's results, but also for designing effective science communication materials.

Authentic portrayals of scientific decision-making processes emphasize transparency, personal engagement, and epistemic openness (Molleda, 2010; Saffran et al., 2020). In this approach, scientists explicitly articulate the factors they consider before making a decision. For example, in bat ecology, when determining sample size, researchers must weigh animal welfare, budget constraints, and methodological considerations. This type of portrayal not only presents the final decision but also highlights the uncertainties and the iterative nature of scientific inquiry. Such transparency fosters trust and strengthens the connection between scientists and their audience (Hovland et al., 1953; Schriebl et al., 2023).

In contrast, standardized portrayals, often found in scientific literature, offer a *post hoc* reconstruction of the research process. While addressing similar topics (e.g., sample size trade-offs, dealing with unexpected results, material selection, and reflections on the nature of science), these portrayals focus on the final decision. The decision is presented first, followed by an explanation of the rationale behind it, without verbalizing the deliberative process itself. This approach presents science as a polished, well-thought-out, and often finalized process (Düsing et al., 2025).

Beyond communication style, the *medium* through which scientific information is conveyed plays a significant role in shaping audience perceptions. Text-based formats encourage detailed analysis and critical reflection, allowing readers to process complex ideas at their own pace (Rovai & Wighting, 2005). Video-based formats, on the other hand, leverage visual and auditory modalities to enhance accessibility and emotional engagement, catering to diverse learning preferences (Liu et al., 2022; Zydney et al., 2012). Videos are particularly effective in creating a sense of social presence, which can strengthen perceived credibility and trust in scientific communication (Garrison et al., 1999).

To explore these dynamics, the study employs a 2 x 2 factorial design, manipulating two independent variables: the presentation of scientific practices (*cookbook-style* vs. *scientific reasoning style*) and the portrayal of scientists' thought processes (*science-in-the-making* vs. *ready-made science*). These conditions were implemented in two different media formats, text and video, to examine whether the effects generalize across modalities. Rather than comparing the media formats directly, the study tests whether the hypothesized effects remain consistent across both formats, thereby enhancing the generalizability of the findings.

The study emphasizes the importance of transparency in the research process and the need to convey the inherent uncertainties in scientific work (Jain et al., 2014; Lederman & O'Malley, 1990). While detailed explanations enhance understanding for audiences with sufficient prior knowledge, minimizing cognitive load through simplified explanations benefits those less familiar with scientific concepts. Similarly, *science-in-the-making* portrayals foster transparency and trust, while *ready-made science* emphasizes professionalism and objectivity. Although the study does not tailor content to individual participants, it acknowledges that audience characteristics, such as prior knowledge, may moderate the effects of communication style and medium. By systematically examining these variables, this research seeks to provide actionable insights for educators and communicators striving to improve public understanding of scientific processes and build greater trust in science.

Recent research suggests that authenticity in science communication is a multifaceted construct, encompassing elements such as transparency, personal engagement, and epistemic openness (Molleda, 2010; Schriebl et al., 2023). Transparency involves openly addressing uncertainties and the evolving nature of scientific findings, while personal engagement highlights the human side of scientific work, including scientists' motivations, values, and deliberations. Epistemic openness emphasizes the provisional nature of knowledge and the methods of scientific inquiry. Together, these facets contribute to the perception of authenticity, aligning with the concept of social presence and increasing the perceived connection between the audience and the communicator (Short et al., 1977).

In contrast*, ready-made science* communication follows standardized scientific norms, aiming to maintain objectivity and professionalism but may be perceived as more distant or impersonal (Fischhoff & Davis, 2014). By integrating both factors in a controlled experimental design, this research examines their combined effects on audience perceptions, comprehension, and trust in science.

3.1.4 Present Research and Hypotheses

In two experimental studies, we utilized identical material that differed only in format: a *text-based presentation in Study 1* and a *video-based presentation in Study 2*. The content focused on research in bat ecology, based on a real field study conducted by a wildlife research institute. The overarching research question for both studies was: How does the presentation of scientific practices and the portrayal of the scientist's thought processes influence the perceived tentativeness and credibility of research findings?

We formulated the following hypotheses:

3.1.4.1 Perception of the Scientist's Credibility.

H1: A scientist who transparently communicates their reasoning processes (*science-in-the-making*) will be perceived as more credible than a scientist who presents only polished, finalized results (*ready-made science*).

3.1.4.2 Perception of the Credibility of Research Findings

H2: Presenting the scientific process with explanations (*scientific reasoning style*) will lead to the research findings being perceived as more credible than presenting the process without explanations (*cookbook-style*).

H3: A presentation adopting the *science-in-the-making* approach, transparently showcasing the evolving nature of scientific inquiry, will enhance the perceived credibility of the research findings compared to a presentation following the *ready-made science* approach, which emphasizes finalized results and standardized argumentation structures.

3.1.4.3 Perceived Tentativeness of Research Findings

H4: Presenting the scientific process with explanations (*scientific reasoning style*) will lead to research findings being perceived as more tentative, reflecting the ongoing nature of scientific inquiry, compared to presenting the process without explanations (*cookbook-style*).

It remained an open research question whether interaction effects between the two independent variables would occur for any of the dependent variables. The research hypotheses and analysis plans for both studies were preregistered prior to data collection on AsPredicted.org (Study 1: https://aspredicted.org/z9c6-svt7.pdf; Study 2: https://aspredicted.org/t2jn-ccmd.pdf).

3.1.5 Ethics Statement

Both studies received approval from the Institutional Ethics Committee of the Leibniz-Institut für Wissensmedien (Approval number: LEK 2023/055). All participants were volunteers, and their identities were kept anonymous. Participants were thoroughly informed about privacy protection measures and their right to withdraw from the study at any time without consequences. Written informed consent was obtained from all participants prior to their participation. A debriefing session was conducted at the conclusion of the experiments.

3.1.6 Power Analysis

An *a priori* power analysis was conducted to determine the required sample size for both studies. The analysis was based on a 2 x 2 between-groups analysis of variance (ANOVA). Given the exploratory nature of the research and the absence of prior empirical data at the outset, a medium effect size ($f = 0.25$) was assumed in accordance with Cohen's (1988) conventions. With an alpha level of $\alpha = .05$ and a desired power of .80, the required total sample size was calculated to be $n = 128$ (approximately 32 participants per condition). This sample size was deemed sufficient to detect main and interaction effects of medium magnitude.

Following the completion of Study 1, the observed data served as a reference point for refining the sample estimation for Study 2. The mean differences observed between conditions in Study 1 were approximately 0.35 points on the 7-point scales used for the dependent variables, with an average standard deviation of about 1.2. Based on these empirical values, an adjusted power analysis indicated that a total sample size of $n = 100$ participants ($n = 25$ per condition) would be adequate to achieve 80% power at an alpha level of .05.

However, to increase the robustness of the results and to account for potential variability or deviations from the initial assumptions, a larger sample size was targeted for Study 2 (n = 160; 40 participants per condition). This decision ensured greater sensitivity for detecting smaller or less consistent effects and maintained sufficient statistical power in case of exclusions or missing data. Retaining a larger sample also improved the reliability and generalizability of the findings across both studies.

3.2 Study 1: Text-Based Presentation

3.2.1 Methods

3.2.1.1 Sample

Participants were recruited via the University of Tübingen mailing list and notices posted on university buildings in Tübingen. Participation was voluntary. To be eligible, individuals had to be at least 16 years old and have a good command of the German language. In appreciation for their participation, they were entered into a draw to win gift vouchers worth 3 × 50 Euros and 2 × 25 Euros.

Data were initially collected from N = 110 participants. To ensure data quality and meaningful interpretation of the dependent variables, we applied the following exclusion criteria: three participants did not provide informed consent; six participants had missing or invalid responses on key variables (including the attention-check item, which asked about the bat species featured in the material, the data-withdrawal item, or at least one dependent measure such as perceived credibility or tentativeness); and two participants showed no engagement with the material, indicated by missing responses to the species question.

After applying these criteria, the final sample comprised n_1 = 99 participants. Of these, 62 identified as women, 34 as men, two as non-binary, and one person did not disclose their gender. The mean age of participants was M = 24.57 years (SD = 6.80). Educational backgrounds were diverse: 57.6% had completed a university entrance qualification, 35.4% held a university degree, and 7.1% reported other qualifications. Most participants studied medicine, health sciences, sports science, or psychology, with additional representation from mathematics and science, education and teaching, and other disciplines.

3.2.1.2 Design and Procedure

The study followed a 2 x 2 between-groups experimental design. Participants were randomly assigned to one of four conditions that varied in how scientific practices were presented (*cookbook-style* vs. *scientific reasoning style*) and how scientists' thought processes were portrayed (*science-in-the-making* vs. *ready-made science*). These variations reflect different modes of communicating scientific reasoning and processes, rather than differences between individual scientists. We collected data from participants in the following conditions: "science-in-the-making – cookbook-style" ($n = 26$), "science-in-the-making – scientific reasoning style" ($n = 22$), "ready-made science – cookbook-style" ($n = 24$), and "ready-made science – scientific reasoning style" ($n = 27$).

After recruitment, participants completed the study online and were required to read one of four texts. These texts were film scripts of the videos used in Study 2. The material was developed for use in educational settings to provide students with deeper insights into both the practice of fieldwork and the principles underpinning the process of scientific inquiry. Our narrative approach to illustrating the research process and fostering scientific literacy was grounded in the structural model of scientific reasoning (Mayer et al., 2008).

The experimental material addressed three key process dimensions:

1. Formulating the research question and hypothesis,
2. Planning and conducting an investigation, and
3. Analyzing and interpreting data.

To ensure data quality, all participants who did not engage with the text or who failed the attention-check question were excluded from analysis. The attention check asked about the bat species presented in the material to confirm active engagement with the content.

To examine the material's impact and the relationships between the dependent variables, each group completed questionnaires measuring the following constructs:

- Perception of the scientist's credibility,
- Perception of the credibility of research findings, and
- Perceived tentativeness of research findings.

3.2.2 Material and Measures

3.2.2.1 Text-Based Presentation

Participants read a text that represented the video scripts used in Study 2. The material explained scientific research processes based on a field study on bat ecology in Thailand (see Table 3). The texts consisted of 1,900 to 2,420 words, with a median reading time of around 8 minutes.

Table 3

Explanation of the Conditions

Presentation of scientific practices	**Video script excerpts**
Cookbook-style	As Daniel is very familiar with the current state of knowledge, his research question is: How does the use of airspace differ between the bulldog and tomb bat?
Scientific reasoning style	Daniel starts by looking at the current state of knowledge about the two bat species. However, current knowledge about bats is limited. This is not only true for knowledge about bats, but also for scientific knowledge in general. Overall, very little is known about these two species. Having analyzed the previous studies in detail, Daniel can continue his search for new knowledge and formulate his research question. This is: How does the use of airspace differ between the bulldog and tomb bat? The research question is the basis for further investigation and should be answered at the end.

Portrayal of the scientist's thought processes	**Video script excerpts**
Science-in-the-making	- Biologist Daniel wants to find out more about the flying behavior of these wild animals. He investigates the ecology of bats. In Daniel's current study, he is also looking for answers about the ecology of bats. -"All the values are summarized in the tables, but you can't see so much in the tables. It's much easier to visualize the values as a graph." Authentic decision to visualize data for better interpretability. -"There are always unexpected values, particularly large or particularly small values, where you have to consider whether these values really come from the animals or whether there are technical problems." Authentic reflection on data quality and measurement uncertainty.
Ready-made science	- Biologist Daniel is familiar with the flight behavior of these wild animals. He is an expert in the ecology of bats. Daniel's current study also focuses on the ecology of bats. -"The result of the statistical test shows that the flight altitudes of the two species of bats are systematically different." Daniel has already defined the test in his experimental design. This illustrates disciplinary authenticity through standardized hypothesis testing. - To relate the results to the hypothesis, Daniel revisits the prediction he made at the beginning of the study. The data matches the prediction. Following standard hypothesis testing procedures, the hypothesis is retained.

3.2.2.2 Perception of the Scientist's Credibility

The perception of the scientist's credibility was assessed using 14 items from the Muenster Epistemic Trustworthiness Inventory (METI) questionnaire (Hendriks et al., 2017), utilizing a 7-point semantic differential scale. This instrument is specifically designed to evaluate trustworthiness judgments toward individuals who share their knowledge publicly, making it well-suited for measuring how laypersons assess experts.

The 14 items were structured as bipolar adjective pairs covering three dimensions of epistemic trustworthiness: expertise, integrity, and benevolence. The scale ranged from 1 (negative pole) to 7 (positive pole) and included examples such as "Incompetent – competent" (expertise), "Dishonest – honest" (integrity), and "Immoral – moral" (benevolence). The internal consistency of the overall scale was excellent ($\alpha = .93$).

3.2.2.3 Perception of the Credibility of Research Findings

Participants' perceptions of the scientific credibility of the research findings were measured using a 7-point semantic differential scale. The questionnaire was based on items from the METI (Hendriks et al., 2017) and the Perceived Scientific Credibility Scale (Kimmerle et al., 2015).

The scale ranged from 1 (negative pole) to 7 (positive pole) and included bipolar adjective pairs such as "Not credible – credible," "Not trustworthy – trustworthy," and "Not reliable – reliable." Participants were instructed to indicate their opinion for each pair of adjectives. The internal consistency of the scale was excellent ($\alpha = .93$).

3.2.2.4 Perceived Tentativeness of Research Findings

To evaluate participants' perceptions of the tentativeness of the research findings, we employed the Perceived Tentativeness Scale (Feinkohl et al., 2016; Flemming et al., 2017, 2020). This scale comprises six statements rated on a 7-point Likert scale ranging from 1 (*I don't agree at all*) to 7 (*I fully agree*). Higher scores indicate greater perceived tentativeness. Example items include: "The results of the study are not very definite," "The study is conclusive" (*reversed*), and "The results of the study should be viewed as tentative."

The German version was adapted to the context of bat ecology. After re-coding reversed items, we computed mean scores across all items. The internal consistency of the scale was moderate ($\alpha = .65$), which is considered acceptable for exploratory stages of research.

3.2.2.5 Correlation Analysis

Because the main analyses relied on ANOVAs, correlation analyses were conducted only to explore the relationships among the dependent measures. Pearson correlation coefficients were computed to examine the linear associations between the three scales. This exploratory step served to assess convergent and discriminant validity rather than to test hypotheses. A significant level of $p < .05$ was used for all tests.

3.2.3 Results

3.2.3.1 Hypotheses Testing

To test the hypotheses, we conducted separate two-way ANOVAs.

Perception of the Scientist's Credibility. Neither the portrayal of the scientist's thought processes, $F(1, 95) = 0.01$, $p = .938$, nor the presentation of scientific practices, $F(1, 95) = 1.50$, $p = .224$, showed main effects for the perception of the scientist's credibility. Additionally, the interaction effect between the portrayal of the scientist's thought processes and the presentation of scientific practices was not significant, $F(1, 95) = 0.02$, $p = .882$. Thus, H1 was not supported.

Perception of the Credibility of Research Findings. No main effects emerged for portrayal, $F(1, 95) = 1.31$, $p = .256$, or presentation, $F(1, 95) = 1.43$, $p = .236$. The interaction was non-significant, $F(1, 95) < 0.01$, $p = .972$. Accordingly, H2 and H3 were not supported.

Perceived Tentativeness of Research Findings. A significant main effect of the presentation of scientific practices emerged, $F(1,95) = 5.94$, $p = .017$, $\eta_p^2 = .06$. Participants in the *cookbook-style* condition without explanation rated tentativeness, on average, higher ($M = 4.00$, $SD = 0.80$) than those in the *scientific reasoning style* condition with explanations ($M = 3.66$, $SD = 0.53$). This result was opposite to the expected direction of H4.

A trend was observed for the main effect of the portrayal of the scientist's thought processes, $F(1,95) = 3.56$, $p = .062$, $\eta_p^2 = .04$. On average, findings presented as *science-in-the-making* ($M = 3.95$, $SD = 0.80$) were rated slightly higher in tentativeness compared to findings presented as *ready-made science* ($M = 3.71$, $SD = 0.57$).

The interaction effect was not significant, $F(1,95) = 1.73$, $p = .191$.

3.2.3.2 Further Analysis: Correlation Analysis

The results of the Pearson correlation coefficients provide valuable insights into the relationships among the various scales. Three correlations were examined to explore these associations (see Table 4).

Table 4

Correlation Matrix of Study 1

	Tentativeness of research findings	**Credibility of research findings**
Credibility of research findings	−.64***	—
Scientist's credibility	−.46***	.65***

Note. ***$p < .001$

A significant negative correlation was found between the perceptions of the tentativeness of research findings and the credibility of research findings (Pearson's $r = -.64$, $p < .001$), suggesting a strong inverse relationship. Additionally, a moderate but significant negative correlation was observed between the perceived tentativeness of research findings and the perception of the scientist's credibility (Pearson's $r = -.46$, $p < .001$). Lastly, a strong and significant positive correlation was identified between the perceptions of the credibility of research findings and the credibility of the scientist (Pearson's $r = .65$, $p < .001$).

3.2.4 Discussion

The hypothesis tests results highlight the pivotal role of presentation in shaping perceptions of scientific tentativeness. While depictions of scientists' thought processes and interaction effects did not significantly affect other measured scales, H4 produced an unexpected outcome: omitting an explanation increased perceived tentativeness, contradicting our initial assumption. This finding suggests that limited contextual information may amplify perceptions of uncertainty.

Correlation analyses offered additional insights. Perceived tentativeness exhibited a strong negative association with research credibility and a moderate negative association scientist credibility, indicating that greater tentativeness undermines perceived trustworthiness. Conversely, research and scientist credibility were strongly positively correlated, underscoring their interdependence in participants' evaluations.

These patterns align with broader concerns about deficits in scientific literacy, as highlighted in earlier research (Bell et al., 2003; Broadhurst, 1970; Duschl, 1988; Lederman & O'Malley, 1990; Matthews, 1994). Participants' responses suggest a limited understanding of the dynamic and iterative nature of scientific inquiry, which may contribute to their reliance on perceived certainty as a marker of credibility. The findings are consistent with previous studies emphasizing the challenges of communicating scientific uncertainty (Flemming et al., 2020; Hendriks et al., 2016b; Kimmerle et al., 2015). High perceived tentativeness can erode public trust in scientific claims (Flemming et al., 2020), further underscoring the need for communication strategies that convey the iterative and uncertain nature if science while maintaining credibility, particularly for decision-makers who depend on scientific insights for informed choices.

Although effective communication of uncertainties did not diminish the credibility of the scientist or the research findings, it appeared to shift focus toward the perceived tentativeness of research findings. This dynamic suggests that while transparency may bolster credibility, it simultaneously alters how the provisional nature of findings is perceived. These results complicate Fischhoff and Davis's (2014) assertion that fostering a deeper understanding of scientific processes improves decision-making and promotes broader knowledge acquisition. If transparency significantly enhances perceived credibility to the point where it inversely correlates with perceived tentativeness, even when tentativeness is explicitly communicated, it raises critical questions about the practical feasibility of leveraging transparency to simultaneously strengthen trust and accurately convey the provisional nature of scientific findings.

Expanding on these findings, Study 2 explored whether video-based presentations yield similar patterns. Multimedia formats, combining visual and auditory elements, may alter perceptions of tentativeness and credibility compared to text-based materials. Research indicates that video presentations can reduce perceived uncertainty (Lim & Benbasat, 2000), potentially mitigating the effects of tentativeness observed in textual formats. This comparative approach provides critical insights into the role of presentation styles in interpretations of scientific information. By examining the interplay between media formats and perceptions of scientific uncertainty, this study contributes to a deeper understanding of how to foster scientific literacy and trust in research outcomes.

3.3 Study 2: Video-Based Presentation

3.3.1 Methods

3.3.1.1 Objective

Building on the findings of Study 1, Study 2 aimed to examine whether video-based presentations produce effects on participants' perceptions that differ from those observed with text-based materials. Given the growing prominence and documented effectiveness of videos in science communication and education (Berk, 2009; Criswell et al., 2022; Forsythe et al., 2022; Grosser et al., 2019), we hypothesized that videos would exert a more pronounced and qualitatively distinct influence on perceptions compared to texts. Videos offer unique advantages, such as the ability to combine auditory and visual elements, which can make complex information more accessible and engaging. By visually illustrating each step of the research process (e.g., including research questions and hypotheses as well as scientific box plots for graphical presentation of results), the videos aimed to create a more immersive and intuitive learning experience, potentially enhancing participants' comprehension. Moreover, the dynamic nature of videos allows for the integration of narrative techniques, animations, and visual cues that can highlight key aspects of the research, making abstract concepts easier to grasp and more relatable. These features make videos particularly well-suited to fostering a deeper understanding of scientific processes, especially for audiences with diverse learning preferences.

3.3.1.2 Sample

Data were initially collected from $N = 210$ participants. To be eligible, individuals had to be at least 16 years old and have a C1 level of German proficiency. Recruitment was conducted via the University of Tübingen's mailing list and on-campus notices. As a thank-you for participating, we raffled git vouchers worth 2 × 50 Euros and 4 × 25 Euros, redeemable at various online retailers.

To ensure data quality and meaningful interpretation of the dependent variables, exclusion criteria similar to those used in Study 1 were applied. Participants were excluded if they did not provide informed consent, withdrew their data, gave incorrect answers to the attention-check question, or showed insufficient engagement with the material (e.g., watched less than 10 minutes of the video). Additional exclusions were made in cases of missing or implausible responses in central measures or technical issues such as duplicate entries.

After applying these criteria, the final sample comprised n_2 = 184 participants (131 women, 49 men, 4 non-binary), with an average age of M = 30.10 years (SD = 14.50). The educational background of participants varied: 50.8% held a university degree, 34.4% had completed a university entrance qualification, and 14.8% had other qualifications. Their main fields of study included mathematics, natural sciences, medicine, health sciences, psychology, and education.

3.3.1.3 Design and Procedure

The study followed a 2 × 2 between-groups experimental design, mirroring the structure of Study 1. Participants were randomly assigned to one of four experimental conditions that varied in how scientific practices were presented (*cookbook-style* vs. *scientific reasoning style*) and how scientists' thought processes were portrayed (*science-in-the-making* vs. *ready-made science*). These variations reflected different modes of communicating scientific reasoning and processes, rather than differences between individual scientists.

Participants were excluded if they did not watch at least 10 minutes of the video or failed the attention check question, which asked about the bat species presented in the material to confirm active engagement with the content. The final analysis included four conditions: "science-in-the-making – cookbook-style" (n = 42), "science-in-the-making – scientific reasoning style" (n = 47), "ready-made science – cookbook-style" (n = 43), and "ready-made science – scientific reasoning style" (n = 51).

To examine the material's impact and the relationships between the dependent variables, each group completed questionnaires measuring the perception of the scientist's credibility, the credibility of research findings, and the perceived tentativeness of those findings.

The same instruments as in Study 1 were used to ensure methodological consistency. Reliability analyses indicated that the Perceived Tentativeness Scale showed moderate internal consistency (α = .60), while both the Perceived Scientific Credibility Scale and the METI demonstrated high reliability (α = .91).

3.3.2 Material and Measures

3.3.2.1 Video-Based Presentation

Participants watched videos documenting a real scientific research process on bat ecology in Thailand, illustrating the entire process from start to finish. The videos were produced by a professional media company in collaboration with educational experts and were based on previously developed scripts. These scripts were translated into four distinct video versions, each lasting between 14 and 18 minutes. The videos aimed to effectively visualize and explain scientific research, providing a more dynamic and engaging learning experience compared to text-based materials. This format was expected to enhance participants' understanding of the research process and reduce misconceptions about scientific tentativeness and credibility.

3.3.3 Results

3.3.3.1 Hypotheses Testing

To analyze our hypotheses, we conducted separate two-way ANOVAs.

Perception of the Scientist's Credibility. A two-way ANOVA revealed no statistically significant effects of portrayal, $F(1, 179) = 0.01$, $p = .930$, or presentation $F(1, 179) = 3.69$, $p = .056$, $\eta_p^2 = 0.02$, nor a significant interaction between the two factors, $F(1, 179) = 0.04$, $p = .845$.

Although the main effect of presentation type approached statistical significance, the mean difference between conditions was small, approximately one-fifth of a scale point. Participants in the *cookbook-style* (without explanation) condition rated the scientist's credibility slightly lower ($M = 5.95$, $SD = 0.77$) than those in the *scientific reasoning style* (with explanation) condition ($M = 6.16$, $SD = 0.58$). This marginal tendency was consistent across both portrayal conditions, suggesting that the presentation style exerted only a negligible influence on perceived credibility of the scientist. Overall, the data does not support H1, indicating that the scientist's perceived credibility remained largely stable regardless of how the scientific reasoning process was presented.

Perception of the Credibility of Research Findings. The ANOVA revealed a significant main effect of the presentation of scientific practices on the perceived credibility of the research findings, $F(1,179) = 10.14$, $p = .002$, $\eta_p^2 = 0.05$. Participants in the *scientific reasoning style* (with explanation) condition rated the credibility, on average, higher ($M = 6.31$, $SD = 0.73$) compared to those in the *cookbook-style* (without explanation) condition ($M = 5.96$, $SD = 0.76$). This finding supports H2, suggesting that providing explanations enhances the perceived credibility of the research findings.

The main effect of portrayal type was not significant, $F(1,179) < 0.01$, $p = .988$. Similarly, the interaction effect between portrayal of the scientist's thought processes and the presentation of scientific practices was not significant, $F(1,179) = 0.11$, $p = .738$.

Perceived Tentativeness of Research Findings. The ANOVA results indicated that neither the portrayal $F(1, 179) = 0.06$, $p = .805$, nor the presentation $F(1, 179) = 2.62$, $p = .108$, or their interaction $F(1, 179) = 0.46$, $p = .498$ had a significant effect on the perceived tentativeness of the research findings. Thus, H4 was not supported by the data.

3.3.3.2 Further Analysis: Correlation Analysis

The correlation analysis conducted in Study 2 yielded insightful findings regarding the relationships among the various scales. The results of the Pearson correlation coefficients revealed several key associations (see Table 5).

Table 5

Correlation Matrix of Study 2

	Tentativeness of research findings	**Credibility of research findings**
Credibility of research findings	−.53***	—
Scientist's credibility	−.41***	.69***

Note. ***$p < .001$

A significant negative correlation was found between the perception of the tentativeness of research findings and the credibility of those findings (Pearson's $r = -.53$, $p < .001$). Furthermore, a negative correlation was observed between the perceived tentativeness of research findings and the perception of the scientist's credibility (Pearson's $r = -.41$, $p < .001$). Lastly, a strong and significant positive correlation was identified between the perception of the credibility of research findings and the credibility of the scientist (Pearson's $r = .69$, $p < .001$).

3.3.4 Discussion

The findings of the correlation analysis in Study 2 offer valuable insights into the relationships between participants' perceptions of scientific tentativeness, the credibility of research findings, and the scientist's credibility. The significant negative correlations between perceived tentativeness and both the credibility of research findings and the scientist's credibility suggest that when research findings are perceived as tentative or uncertain, they are viewed as less credible. This aligns with previous studies (Flemming et al., 2015, 2020; Hendriks et al., 2016b; Kimmerle et al., 2015), which also found that uncertainty in research is often associated with a decrease in perceived credibility.

Despite efforts to emphasize that tentativeness is inherent in the scientific process and not indicative of poor research quality, participants who perceived the findings as more tentative also tended to rate them as less credible. This underscores a key challenge in science communication: the tendency to conflate scientific uncertainty with unreliability. Prior research has shown that lay audiences often interpret epistemic uncertainty, such as tentative language or provisional findings, as a signal of low evidence quality, which can undermine trust in both the information and the scientist, even when uncertainty is appropriately communicated (Flemming et al., 2020; Schneider et al., 2022; van der Bles et al., 2019).

Furthermore, the strong positive correlation between the perceived credibility of the scientist and the credibility of the research findings supports the notion that these two dimensions are closely intertwined in the minds of participants. This finding underscores the importance of fostering trust not only in scientific results but also in those who produce and communicate them. Participants who perceived the scientist as more credible also tended to express greater trust in the research presented. While this correlation does not imply causality, it suggests that perceptions of a scientist's credibility are closely linked to how trustworthy their findings are judged to be. This pattern aligns with prior research indicating that perceived credibility of scientists is associated with increased acceptance of scientific claims, even when the direction of influence remains unclear (Hendriks & Jucks, 2020; Kreps & Kriner, 2020; Wintterlin et al., 2022). This connection underscores the critical role of scientist credibility in shaping public perceptions of scientific findings and highlights the need for science communicators to foster trust in both research and the individuals conducting it.

These results further contribute to our understanding of how scientific uncertainty is communicated and perceived. While transparent presentation of scientific knowledge is essential, the current findings suggest that communicating uncertainty may inadvertently diminish the perceived credibility of research. This echoes previous studies showing that the public often struggles to accept scientific uncertainty without it undermining trust in the findings themselves (Fischhoff & Davis, 2014; Simis, 2013). In light of these findings, future research should explore strategies for communicating uncertainty in ways that preserve both the credibility of the findings and trust in the scientists who produce the research. Additionally, the negative correlation between perceived tentativeness and both credibility scales suggests that participants may have difficulty reconciling the provisional nature of scientific knowledge with their expectations of certainty and trustworthiness. Despite efforts to clarify that scientific research is an ongoing process, the perception of uncertainty was associated with increased doubts about the reliability of the findings. This highlights a persistent issue in science communication: how to balance the need for transparency with the need to maintain public confidence in science.

The ANOVA revealed that the presentation of scientific practices significantly impacted the perceived credibility of research findings. Participants who received an explanation rated the credibility higher than those who did not. This suggests that, while explanations of uncertainty alone may not suffice to enhance credibility, explanations of scientific practices can positively influence how credible research is perceived.

The absence of significant effects on perceived credibility suggests that variations in communicative framing did not lead participants to evaluate the scientist more or less favorably. This stability in perceived credibility may be considered a positive outcome for science communication, as it indicates that efforts to increase transparency or authenticity do not undermine the scientist's perceived trustworthiness. In other words, communicating uncertainty or making scientists' thought processes visible does not appear to reduce credibility, which may alleviate common concerns among scientists about being perceived as less competent when openly discussing the tentative nature of research.

In conclusion, the findings from this study underscore the complex relationship between the perceived tentativeness of research and its credibility. They highlight the challenge of communicating uncertainty in science in a way that does not undermine trust in the findings or the scientists behind them. These insights have important implications for science communicators, policymakers, and researchers, who must carefully navigate the delicate balance between transparency and trust in their efforts to engage the public with scientific knowledge.

3.4 General Discussion

Understanding the intricate relationship between the presentation of scientific practices, scientific uncertainty, and public trust is crucial for advancing science communication practices and fostering scientific literacy. The findings of the research presented here underscore the pivotal role of how scientific practices are presented in shaping perceptions of tentativeness and credibility. This research highlights the importance of balancing perceptions of tentativeness and credibility, ensuring they are not perceived as inherently opposing attributes. Both studies revealed negative correlations between the perceived tentativeness of research findings and the credibility of both the scientist and their research. These results emphasize the need for communication strategies that transparently convey scientific uncertainty while maintaining trust in the credibility of the findings and the scientist. By exploring how different presentation formats influence people's perceptions, the findings provide valuable insights for both researchers and practitioners of science communication.

3.4.1 Key Findings and Interpretations

3.4.1.1 Presentation Formats

Shorter text-based explanations were more effective in influencing perceptions of tentativeness, suggesting that brevity and clarity increase awareness of uncertainty. In contrast, video-based presentations showed no significant effects on perceived tentativeness, indicating potential differences in how people process information across modalities. These findings suggest that while text-based materials may encourage straightforward interpretation, the multimodal nature of video presentations could dilute perceived tentativeness. Future studies should explore how the richness of video presentations might be optimized to clarify uncertainty without compromising credibility. These findings highlight the role of cognitive demands in shaping audience perceptions, with text encouraging more analytical processing and video potentially fostering a broader, less detail-focused engagement.

3.4.1.2 Credibility and Tentativeness of Research Findings

Both studies consistently revealed a negative correlation between perceived tentativeness and the credibility of research findings. This suggests that while acknowledging uncertainty enhances understanding of the provisional nature of science, it can inadvertently diminish trust in the findings. Balancing these perceptions is crucial, particularly in contexts where public trust in science is critical, such as public health, climate science, and emerging technologies. By integrating these findings into science communication strategies, future efforts can focus on refining presentation methods and improving experimental manipulations to achieve a more balanced and effective communication strategy. For instance, the findings highlight the need for nuanced approaches to address the trade-off between transparency and credibility. These approaches should consider tailoring messages to specific audiences while maintaining a consistent focus on the dynamic nature of scientific knowledge (Fischhoff & Davis, 2014; Gustafson & Rice, 2019; Simis, 2013).

3.4.1.3 Educational Implications: Promoting Scientific Literacy

To address misconceptions about the tentativeness and credibility of scientific research, educational resources should prioritize fostering scientific literacy. Educational resources must emphasize that science is not a static body of knowledge but a dynamic, evolving process. It is essential to highlight the iterative nature of science. By discussing how research evolves with new data and findings, students might better understand that science is a continuous cycle of testing, refining, and revising theories. This process would help them appreciate the provisional nature of scientific knowledge.

Understanding tentative findings is also crucial. It is important to teach students those tentative findings, whether from early fieldwork, climate models, or preliminary medical trials, are not failures, but rather vital steps toward more robust conclusions. Recognizing the value of uncertainty in research as a natural and necessary part of scientific progress, rather than a sign of unreliability, is essential for developing a nuanced understanding of science (Matthews, 1994; Pielke, 2008).

Our studies underline the significance of transparent communication in science education, particularly regarding the provisional nature of scientific knowledge. The results suggest that the presentation of scientific practices can influence how students perceive the credibility of scientific findings. By offering either detailed explanations (*scientific reasoning style*) or no explanations at all (*cookbook-style*), and by portraying scientists as either authoritative figures (*ready-made science*) or authentically reasoning individuals (*science-in-the-making*), educators can shape how students perceive science and its credibility. Enhancing understanding of the scientific process is essential. Students who understand how scientific inquiry works, such as hypothesis testing and theory revision, are more likely to see science as a dynamic, evolving field rather than a fixed collection of facts.

To foster a deeper appreciation of the scientific process, curricula should incorporate both procedural and epistemic knowledge. This includes teaching not only the "what" of scientific activities but also the "why" and "how." Emphasizing that scientific knowledge is provisional, evolving with new evidence, and that uncertainty is a necessary part of this process is vital. By integrating these principles into educational resources, we can help students critically engage with scientific content, reducing misconceptions about science's reliability and fostering scientific literacy.

Explicitly addressing the relationship between tentativeness and credibility could help learners develop the critical thinking skills needed to evaluate scientific claims. For example, case studies showing how tentative findings have led to significant breakthroughs can help normalize uncertainty as part of the scientific process (Chen & Min Song, 2017; Yang & Deng, 2024).

3.4.1.4 Strengths and Weaknesses of the Studies

The studies presented offer significant insights into the field of science communication and science education, particularly regarding the ways in which uncertainty and credibility are perceived by scientific laypeople. One of the main strengths of these studies lies in their methodological diversity. By combining both text- and video-based presentations, the research enabled a more nuanced analysis of how different formats affect the perception of scientific uncertainty and credibility. This approach provided a rich dataset that captures the complexities of communicating science across various media, which is particularly valuable in today's media landscape.

Furthermore, the findings offer suggestions for communicating scientific uncertainty, which is crucial for fostering public trust and engagement in critical scientific issues. These insights could inform communication strategies that help bridge the gap between scientific experts and the public, particularly in contexts where uncertainty is an inherent aspect of the scientific process.

However, there are also notable weaknesses in the studies that should be addressed in future research. A primary limitation is the heavy reliance on self-reported data. While self-reports can provide valuable insights into perceptions and attitudes, they are also susceptible to biases such as social desirability or recall bias, which may distort the findings. Additionally, the sample diversity was limited, with the participant groups not fully representing the broader population. This lack of diversity in the sample raises questions about the generalizability of the results, particularly when it comes to different cultural and demographic groups. Lastly, the studies primarily offer snapshot data, capturing perceptions at a single point in time, without providing insights into how these perceptions evolve over time or with repeated exposure to scientific communication.

3.4.1.5 Future Directions for Research

To address these limitations and build on the strengths of the existing studies, future research should focus on several key areas. First, longitudinal studies could provide valuable insights into how public perceptions of uncertainty and credibility change over time. In fields such as climate science and medicine, where new findings and updates are frequent, understanding how people's views shift as new information is presented could help refine communication strategies. It is particularly important to consider how people's expectations, shaped by prior communication norms, influence their perceptions of credibility. If they are accustomed to scientists being portrayed as authoritative figures presenting immutable facts, they may view scientists who communicate uncertainty as less credible. However, if uncertainty were more routinely incorporated into public understandings of science, these perceptions might shift, allowing for a more accurate view of scientific work as an ongoing, iterative process.

Another area for future research is the diversification of participant samples. Including individuals from a broader range of demographic and cultural backgrounds would enhance the external validity of the findings, making them more applicable to diverse audiences. This is especially crucial in the context of global science communication, where messages need to resonate across different social, cultural, and educational contexts.

Moreover, the studies could be strengthened by integrating objective measurement methods alongside self-reported data. While self-reports provide valuable insights into subjective perceptions, they do not capture the full scope of audience engagement. Future research could include behavioral measures such as audience engagement, trust in scientific sources, and changes in decision-making due to exposure to different communication formats. This objective data could provide a more comprehensive understanding of how different communication strategies influence behavior and perceptions.

Finally, refining the manipulation techniques used in the studies could offer deeper insights into how specific communication elements affect perceptions. By experimenting with more distinct variations in the framing of scientific uncertainty, researchers could isolate the effects of particular aspects of communication, such as the language used to convey uncertainty or the visual presentation of scientific information and gain a clearer understanding of how these factors shape people's understanding.

3.4.1.6 Broader Applications

The findings from these studies offer insights into how to effectively communicate scientific uncertainty. This research lays the foundation for developing communication strategies that can be tailored to various contexts, from public health campaigns to educational outreach programs. Understanding how to communicate uncertainty clearly, accessible, and engaging is crucial for fostering a more informed and scientifically literate public. In an era where scientific knowledge is increasingly complex and rapidly evolving, the ability to effectively convey uncertainty can empower individuals to make more informed decisions, engage with science in meaningful ways, and contribute to the public discourse on pressing scientific issues such as climate change and public health (Chi et al., 2022; Pielke, 2008).

3.5 Conclusion

This research underscores the critical importance of balancing transparency and credibility in science communication. While acknowledging the provisional nature of scientific knowledge is essential for public understanding, it must be communicated in a way that maintains and nurtures trust.

The theoretical foundation for our findings is grounded in two key aspects of scientific communication: Communicating procedural and epistemic knowledge regarding the steps of scientific inquiry, and representing the thought processes of scientists. Educational resources and communication strategies should incorporate these insights to address misconceptions, promote scientific literacy, and encourage critical thinking. By doing so, educators can empower future generations to engage in the complexities of scientific knowledge and foster a deeper understanding between scientists and the public. These efforts may contribute to enhancing the public's ability to engage with scientific topics and make informed decisions (Fischhoff & Davis, 2014; Matthews, 1994).

Transition to Chapter 4

The findings from Chapter 3 provide preliminary evidence that the way scientific processes are communicated can shape perceptions of tentativeness and credibility. However, university students represent a relatively homogenous and highly educated sample. To examine whether these effects generalize to younger learners and more authentic educational contexts, Chapter 4, "Secondary School Student's Perception of Credibility and Tentativeness in Research Process Presentations", extends the investigation to secondary school students.

In this chapter, the same conceptual framework and video materials are tested in two school-based formats: receptive classroom settings and interactive lab-institute settings. By varying the learning context, student age, and instructional format, the study assesses the robustness of the framework and explores how epistemic understanding and credibility judgments develop in more diverse educational environments.

4. Secondary School Students’ Perceptions of Credibility and Tentativeness in Research Process Presentations

Statement of Contribution

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Till Bruckermann	5	2	-	-	4
Anke Schumann	6	2	-	-	-
Miriam Brandt	7	2	-	-	-
Daniel Lewanzik	8	2	-	-	-
Christian C. Voigt	9	2	-	-	-
Ute Harms	10	2	-	-	-
Joachim Wirth	11	2	-	-	-
Ulrike Cress	12	5	-	-	-
Joachim Kimmerle	13	5	-	-	10
Title of Paper	The Impact of Research Process Presentations on Secondary School Student’s Perception of Scientific Credibility and Tentativeness				
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Abstract

Supporting students in understanding how scientific knowledge is developed, including its inherent uncertainty, is a key challenge in science education. The research presented here investigated how the formatting of scientific practices and the representation of a scientist's thought processes influence secondary school student's perceptions of the scientist's credibility, the research's credibility, and the tentativeness of findings. Scientific practices were presented either as *cookbook style* (research without rationale) or with *scientific reasoning style* (explaining *why* each step was taken). The scientist's thought process was shown authentically (*science-in-the-making*, with visible deliberations) or canonized (*ready-made science*, settled steps). Two field studies using bat ecology videos were conducted. In Study 1 (N = 148), students viewed one of four videos corresponding to the experimental conditions. No main effects were found, but perceived tentativeness negatively correlated with both researcher and findings credibility across all conditions. Study 2 (N = 607) was a full-day school intervention with the same four videos in a constructive learning format. A main effect indicated that findings were perceived as more tentative when presented as *science-in-the-making*. Again, negative correlations between tentativeness and credibility were observed in all conditions. These results inform the design of educational media that realistically portray scientific inquiry and help students develop a nuanced view of science as dynamic and provisional. They also point to a potential trade-off: While authentic representations can foster epistemic insight, they may simultaneously lower perceived credibility.
Keywords: tentativeness, research process, credibility, science communication, science education

4.1 Introduction

A central challenge in science education is helping students grasp not only scientific content but also the epistemic processes through which scientific knowledge is constructed. Despite growing calls for authenticity in science instruction, classroom practices often fail to convey the provisional and contested nature of scientific inquiry. This disconnect contributes to a limited understanding of science as a dynamic and socially embedded enterprise. The research presented here responds to this educational problem by investigating how video-based representations of scientific reasoning and researcher deliberation can support students in developing a more nuanced view of science – one that includes both its credibility and its inherent tentativeness.

Understanding and applying scientific methods is a fundamental goal in science education. However, learning about science involves more than acquiring factual knowledge; it requires an understanding of the nature and dynamics of scientific inquiry itself. Despite its centrality, this epistemic dimension is often underrepresented or simplified in classroom settings (Duschl, 2008; Duschl, 1988; Osborne et al., 2003).

Two pedagogical approaches frequently employed to address this gap are inquiry-based learning (IBL) (Friesen & Scott, 2013) and case-based learning (CBL) (McLean, 2016). IBL engages students in generating questions, designing investigations, and analyzing data in ways that simulate aspects of authentic research (Bell et al., 2005; Zion & Mendelovici, 2012). CBL, in contrast, emphasizes historical or contemporary examples to highlight how scientific knowledge is developed in specific contexts (Allchin et al., 2014; Yadav et al., 2010). Both approaches have demonstrated effectiveness in promoting scientific reasoning, yet each has notable limitations. IBL is often operationalized through structured, stepwise protocols that risk oversimplifying the complexity and contingency of real scientific practice (Chinn & Malhotra, 2002). Historical case studies, while rich in contextual detail, typically present science as a finalized product rather than a process in motion, reinforcing the image of science as authoritative and conclusive (Heering, 2015). This contributes to what Latour and Woolgar (1986, 2013) call the 'black box' of science, in which the actual processes of knowledge production remain opaque to learners.

Recent research has emphasized the importance of explicit and reflective approaches to nature of science instruction, which encourage learners to critically engage with the epistemic foundations of scientific knowledge (Erduran & Dagher, 2014; Khishfe & Abd-El-Khalick, 2002). Such approaches aim to make the reasoning behind scientific practices visible and accessible, rather than leaving them implicit or abstract. Video-based instruction has shown particular promise in this regard, especially when it is epistemically framed to highlight the processes of scientific inquiry and decision-making (Erduran et al., 2021). Our research builds on this work by examining how different portrayals of scientific reasoning and researcher deliberation affect students' perceptions of credibility and tentativeness – two dimensions central to scientific literacy.

To address these challenges, we developed an instructional design that integrates core features of both IBL and CBL. Central to this design is a series of professionally produced videos that document an ongoing ecological research project – from the formulation of research questions, through fieldwork and data analysis, to the publication of results. These videos present *science-in-the-making* (Knorr-Cetina, 1999; Latour & Woolgar, 1986, 2013), providing students with epistemic access to the provisional and iterative nature of scientific work. In this way, they align with the goals of CBL by contextualizing scientific reasoning in an authentic case, while also incorporating reflective tasks that invite learners to engage with the epistemic justifications for research decisions, an aspect central to IBL. In Study 2, these videos were extended with structured reflection and application tasks to foster active engagement with the research process. Although students did not design or conduct their own investigations, they were guided to reconstruct and critically evaluate key elements of the inquiry, thus approximating the epistemic practices of scientific reasoning.

Such approaches are crucial for fostering scientific literacy, which includes not only conceptual understanding but also the ability to critically evaluate how scientific knowledge is generated and validated (Lederman & Abell, 2014; Norris & Phillips, 2003). In a digitalized knowledge society, this must be extended to include digital literacy, that is, the capacity to access, interpret, and communicate scientific information across online platforms (Jenkins et al., 2009; Siddiq et al., 2017). As scientific communication increasingly takes place in digital media, students must learn to navigate competing claims and evidence. Developing a nuanced understanding of science as a contested, evolving, and socially embedded enterprise is therefore essential (Feinstein & and Waddington, 2020; McGrew et al., 2017).

Despite increasing emphasis on authenticity in science education, realistic portrayals of scientists and their work remain rare in formal instruction (Archer et al., 2013). Yet, such representations are crucial not only for conveying how science actually works, but also for challenging persistent stereotypes about who does science and under what conditions. Video-based media offer significant potential to make epistemic practices visible, especially when they depict science-in-action rather than as a finalized body of facts (Evagorou et al., 2015). However, it remains underexplored how such portrayals affect students' perceptions of scientific credibility and tentativeness of research findings – two dimensions that are central to scientific literacy but often overlooked in instructional design.

To address these questions, we conducted two empirical studies as part of an interdisciplinary research collaboration spanning biology, science education, psychology, and the learning sciences. Drawing on the educational video series described above, the studies investigated how distinct representations of scientists' thought processes and scientific practices influence students' understanding of scientific inquiry, particularly in terms of their perceptions of the scientist's credibility, the credibility of the research findings, and the perceived tentativeness of those findings. By explicitly examining these relationships, our study contributes to the evidence base for designing educational media that foster epistemically informed engagement with science – while also highlighting potential tensions between authenticity and perceived credibility.

While our study focuses on the effects of video-based representations, we acknowledge that student learning is not solely determined by instructional format. Prior research has shown that students' pre-existing conceptions, epistemological beliefs, and prior experiences strongly mediate how they interpret and respond to educational materials (Kampa & Köller, 2016; Mete, 2024; Schiefer et al., 2022). Our design does not assume a direct causal pathway from video format to perception but rather explores how specific communicative features may interact with students' existing frameworks of understanding.

4.1.1 The Nature of Science and Scientific Reasoning

A deeper understanding of scientific inquiry requires more than familiarity with experimental procedures. It demands insight into the nature of science, including the tentative status of scientific knowledge, the relationship between empirical observation and theoretical interpretation, and the tension between objectivity and subjectivity (Lederman et al., 2002; McComas, 2002). While nature of science is sometimes reduced to a singular, linear scientific method, it is now widely acknowledged that scientific inquiry is multifaceted, context-dependent, and shaped by creativity, prior knowledge, and methodological diversity (Kind & Osborne, 2017; Mete, 2024; Roden, 1999).

These nuances are especially relevant for educational interventions that seek to promote more realistic conceptions of science. Contemporary frameworks position nature of science as a core element of scientific literacy, supporting both conceptual understanding and the capacity to engage critically with science in personal and societal contexts (National Science Teachers Association, 2021). Nature of science also highlights that science is a tentative, creative, and socially embedded enterprise – features that are essential for fostering a more reflective and inclusive view of knowledge (Education, 2021). Empirical evidence suggests that explicit incorporation of nature if science into instruction significantly enhances student's understanding and application of scientific thinking (Namakula & Akerson, 2024).

Closely related to nature of science is the concept of scientific reasoning. This is a cognitive construct that encompasses the ability to solve scientific problems and critically reflects on the reasoning processes involved (Krell et al., 2020; Morris et al., 2012). It is often described through interrelated sub-competencies, including problem definition, hypotheses development, evidence evaluation, and the communication of findings (Opitz et al., 2017). These skills reflect the iterative and integrative nature of scientific work and underscore the value of instructional formats that authentically mirror research processes (National Research Council, 2012).

Effective scientific reasoning depends on the integration of content knowledge with procedural and epistemic understanding (OECD, 2023b). Kind and Osborne (2017) propose distinct styles of scientific reasoning that encompass these dimensions, showing that tasks such as experimentation require not only technical proficiency but also an appreciation of the epistemic foundations of concepts like validity, reliability, and uncertainty (Kind & Osborne, 2017).

In addition, students' scientific reasoning competencies and epistemic beliefs not only shape their own inquiry processes but also influence how they evaluate externally presented research. When confronted with portrayals of scientific inquiry, learners apply their internal epistemic frameworks to assess the credibility of both the researcher and the findings, thereby linking nature of science understanding and scientific reasoning directly to credibility judgments (Kampa et al., 2016; Mete, 2024).

4.1.2 Challenges in Science Education and the Need for New Approaches

While these principles of scientific literacy and reasoning offer a strong conceptual foundation, their implementation in classroom settings remains challenging. Constraints such as curricular standards, time limitations, and teacher preparedness often hinder efforts to integrate the nature of science concept meaningfully into instruction. Erduran (2013) argues that nature of science frameworks must remain sufficiently broad to accommodate developmental and pedagogical variability across educational contexts. In practice, however, this necessary flexibility can lead to under-specification, which may dilute the conceptual richness of nature of science and obscure its epistemic relevance.

Students frequently struggle to understand and apply scientific concepts in authentic ways. Documented difficulties include the abstraction of theoretical models, the disconnect between textbook science and real-world relevance, and a lack of sustained engagement or motivation (Driver et al., 1994; Osborne & Dillon, 2008). Recent findings from PISA 2022 further underscore these issues, revealing declining performance in science and growing educational inequalities tied to socio-economic and cultural backgrounds (OECD, 2023a). These developments highlight the urgent need for adaptive, inclusive, and conceptually coherent instructional approaches.

At the same time, broad and generic representations of science risk oversimplifying its complex, discipline-specific practices, which may limit students' understanding of the epistemic processes that underlie scientific claims. Drawing on situated learning theory (Lave & Wenger, 1991), an alternative approach emphasizes that meaningful learning occurs through participation in authentic scientific practices. From this perspective, science education should not convey factual knowledge, but also foster an understanding of the social, procedural, and epistemic dynamics of knowledge construction.

Importantly, these frameworks foreground the credibility of scientific reasoning, both in terms of the scientist as a knowledge source and the findings they produce. Transparency, methodological rigor, and openness about uncertainty are key criteria by which scientific claims are judged (Allchin, 2011). The provisional and tentative nature of scientific knowledge thus calls for educational designs that make these characteristics visible. Doing so not only enhances students' epistemic insight but also enables more critical and reflective engagement with science.

4.1.3 The Paradox of Scientific Progress and Uncertainty

Traditionally, science has been portrayed as a problem-solving enterprise aimed at reducing uncertainty through controlled experimentation and precise measurement. This image of science as a generator of clear, objective knowledge remains prevalent in education and public discourse. However, modern science increasingly recognizes that uncertainty is not merely a limitation to be overcome, but a fundamental and unavoidable feature of knowledge production – particularly in complex, dynamic, and unpredictable systems (Funtowicz & Ravetz, 1990; Helton et al., 2006).

In fields such as climate science, biomedicine, and psychology, uncertainty arises not only from data variability or measurement error, but also from incomplete theories, evolving models, and the influence of contextual and societal factors. These forms of uncertainty are often irreducible, challenging the ideal of science as a purely deterministic endeavor (Funtowicz & Ravetz, 1990).

Historically, such uncertainty was often downplayed or masked to maintain scientific authority (Kampourakis & McCain, 2019). Today, however, scientific credibility increasingly depends on the transparent communication of uncertainty, acknowledging limitations, model assumptions, and the provisional nature of findings. This shift is not a weakness but reflects a deeper epistemic maturity, that is, recognizing that science progresses not by eliminating all doubt, but by critically engaging with it.

For science education, this reframing of uncertainty holds profound implications. Students must learn to interpret scientific knowledge not as a collection of static facts, but as the outcome of reasoned judgment under uncertainty. Educational approaches that make the tentative and interpretive character of science visible can promote more accurate and critical conceptions of scientific inquiry, including how trust is built in science and how findings are evaluated in light of incomplete evidence.

4.1.4 Understanding Uncertainty and Tentativeness in Scientific Inquiry

Building on the recognition that uncertainty is an inherent feature of scientific knowledge, it is crucial to distinguish between *epistemic uncertainty* – a feature of the knowledge itself – and *tentativeness*, the way in which that knowledge is communicated and evaluated. In this context, *uncertainty* refers to situations where available information is incomplete, ambiguous, or open to multiple interpretations, thus affecting reasoning and decision-making (Fox & Ülkümen, 2011; Kahneman et al., 1982). Scientists deal with uncertainty not as a sign of failure, but as a stimulus for further inquiry, through strategies such as data triangulation, probabilistic reasoning, and adaptive judgement (Gigerenzer & Gaissmaier, 2011; Payne et al., 1993). Especially in complex systems with incomplete evidence and evolving theories, acknowledging uncertainty is essential for methodological rigor and transparency (Funtowicz & Ravetz, 1990; Helton et al., 2006).

Tentativeness, by contrast, refers to the communicative stance of researchers that reflects an awareness of the provisional nature of their claims (Flemming et al., 2020). While uncertainty describes the epistemic quality of a knowledge claim, tentativeness concerns how that claim is framed: whether it is cautiously expressed, explicitly qualified, or open to revision in light of new data. Scientific knowledge thus exists on a continuum from preliminary, exploratory findings to well-established results with high intersubjective reliability. Positioning a claim appropriately along this continuum is crucial for scientific credibility and for helping learners evaluate claims accurately.

In science education, promoting tentativeness as a rhetorical and cognitive practice is key to fostering scientific literacy. Encouraging students to consider alternative interpretations, articulate limitations, and qualify their conclusions promotes intellectual humility and epistemic flexibility. Rather than signaling indecisiveness, tentativeness in science reflects a commitment to evidence-based reasoning and revision, making it a central feature of authentic scientific inquiry and communication.

4.1.5 Theoretical Rationale and Hypotheses

To examine how portrayals of scientific inquiry affect learners' evaluations of science, we developed two key dimensions of video-based science communication that align with distinctions established in science studies and science education literature. These two dimensions reflect contrasting epistemological narratives: one that simplifies and stabilizes science for communicative efficiency, and one that seeks to represent the complexity, tentativeness, and socially embedded nature of real-world inquiry.

We explicitly define these two dimensions as follows:

1. Representation of the scientist's thought process. Contrasting *ready-made science*, where decisions and conclusions appear finalized without visible deliberation, with *science-in-the-making*, where uncertainties, deliberations, and revisions are made visible. This distinction reflects Latour and Woolgar's (1986, 2013) concept of finalized knowledge versus epistemic deliberation.
2. Representation of scientific practices. Contrasting a *cookbook-style* format, presenting sequential procedural steps without epistemic context, with *scientific reasoning style*, which make explicit the rationale, justification, and iterative nature of research decisions. This distinction follows Kind and Osborne's (2017) framework on styles of scientific reasoning.

Prior research on epistemic framing and nature of science instruction suggests that making reasoning and uncertainty visible can foster tentativeness awareness but may challenge credibility perceptions due to lay expectations of scientific certainty (Erduran et al., 2021; Flemming et al., 2020). However, to our knowledge, no prior study has systematically manipulated the transparency of the research process in science communication. This represents a specific research gap that we address in the present study. Our hypotheses are therefore grounded in theoretical considerations about epistemic transparency and the nature of science, while explicitly acknowledging the limited direct empirical precedent.

These dimensions are likely to influence different facets of credibility. Perceptions of the researcher's credibility may be shaped by visible uncertainty and deliberation, which can be interpreted either as openness and intellectual honesty or as lack of competence. In contrast, perceptions of the findings' credibility depend more directly on whether procedures are presented as systematically justified rather than unelaborated steps.

Based on these considerations, we formulated the following hypotheses:

H1: Presenting the scientist's thought process in a *ready-made science* mode will lead to higher perceived credibility of the scientist than presenting it in a *science-in-the-making* mode.

H2: Presenting the scientist's thought process in a *science-in-the-making* mode will lead to higher perceived credibility of the research findings than a *ready-made science* mode.

H3: Presenting scientific practices with explanatory narration (*scientific reasoning style*) will lead to higher perceived credibility of the research findings than a *cookbook-style* presentation.

H4: Presenting scientific practices with explanatory narration will lead to higher perceived tentativeness of the research findings than a *cookbook-style* presentation.

To test these hypotheses, we conducted two experimental studies with secondary school students. Each study used custom-designed educational videos based on authentic fieldwork in bat ecology. The videos varied systematically along two dimensions: (1) whether or not the scientific practices were explicitly explained (*cookbook-style* vs. *scientific reasoning style*), and (2) whether the scientist's thought process was presented in a *science-in-the-making* or *ready-made science* mode. In addition to the hypothesized main effects, we explored possible interaction effects between these two forms of science communication on students' perceptions of scientific credibility and tentativeness. Moreover, we examined potential intercorrelations among the dependent variables, both across the experimental conditions as well as within each of these conditions.

4.2 Method

4.2.1 Design

We conducted two school-based experiments using a 2 x 2 between-groups design, manipulating two independent variables:

- Scientist's thought processes: Whether the scientist's reasoning was presented as *science-in-the-making* (with visible deliberations and uncertainty) or as *ready-made science* (finalized decisions without visible reasoning).
- Scientific practices: Whether the research steps were explained through *scientific reasoning style* (with epistemic justification and explicitly narration) or presented in a *cookbook-style* format (procedural steps only with implicit narration).

This design resulted in four distinct video conditions, each combining one level of each factor. Both studies employed the same four video conditions and identical measurement instruments but differed in instructional format. An overview of the four experimental conditions is provided in Table 6.

To clarify the operationalization of our two factors, we emphasize that the "scientist's thought process" manipulation varied the visibility of epistemic deliberation: in the *science-in-the-making* condition, the scientist verbalized uncertainties and decision-making processes; in the *ready-made science* condition, decisions were presented as finalized. The "scientific practices" manipulation varied the depth of epistemic explanation: in the reasoning styles condition, each research step was justified; in the *cookbook-style* condition, steps were presented without rationale. These distinctions were reflected in the video scripts and systematically controlled across conditions.

Table 6

Overview of Experimental Conditions

Condition	Scientist's Thought Processes	Scientific Practice	Example Sentences from Video Script
Condition 1	Science-in-the-making	Scientific reasoning style	*"Formulating a hypothesis is always an important step, because it permeates the research process like a 'common thread'. It influences the planning and execution of the study."*
Condition 2	Science-in-the-making	Cookbook-style	*"Of course, there is always a trade-off between what you would like to achieve, what data you would like to generate and what is possible."*
Condition 3	Ready-made science	Scientific reasoning style	*"Formulating a hypothesis is important because it influences the planning and execution of the study."*
Condition 4	Ready-made science	Cookbook-style	*"Daniel opts for loggers that measure temperature and air pressure. GPS loggers are too heavy for the small bats."*

4.2.2 Material

All four videos portrayed the same core scientific content: a field-based bat ecology research project conducted in Thailand, investigating the flight altitude of two bat species using miniaturized transmitters. The same scientist appeared in all videos; the variations arose solely from how the research process and the scientist's thought processes were presented.

Video development followed a systematic design framework that integrated insights from science education, philosophy of science, and multimedia learning. The framework structured educational videos across three levels: (1) a macro level that defined chapter structure based on scientific reasoning skills and nature of science categories, (2) a meso level capturing authentic scientific research processes, and (3) a micro level which included specific variations in how scientific practices (*cookbook-style* vs. *scientific reasoning style*) and the scientist's thought processes (*science-in-the-making* vs. *ready-made science*) were communicated.

In our experimental setup, the micro-level dimensions were systematically manipulated:

- Videos in the *scientific reasoning style* condition included explanations for procedural and epistemic choices (the *how* and *why*) across eight phases of research.
- Videos in the *cookbook-style* condition presented only the procedural steps (*what*), omitting justifications.
- Videos in the *science-in-the-making* condition depicted the scientist verbalizing decision-making processes and expressing uncertainties.
- Videos in the *ready-made science* condition presented outcomes as finalized, with minimal insight into cognitive processes.

4.2.3 Procedure

In Study 1, the intervention consisted of a video-only format without accompanying tasks. It was implemented as a single 90-minute session during regular school hours. This time frame was chosen to ensure sufficient room for technical preparation and implementation, including access to iPads, individual headphones for each student, and a stable internet connection. Students watched one of four video versions (18-23 minutes in length, depending on condition) on digital classroom devices under standardized conditions. The videos were streamed via the research project's homepage, which subsequently also provided direct access to the post-video questionnaire. The remaining time of the session allowed for debriefing about the study as well as for students to raise questions regarding the video or the research project in general. No additional tasks or follow-up discussions were included in Study 1. A trained member of the research team moderated each session to ensure procedural fidelity across classrooms. The intervention was designed to isolate the effects of the video content itself, without additional instructional scaffolding or reflection.

In Study 2, the intervention extended the video format by embedding it in a full-day instructional sequence (approximately six hours), conducted at two research institutions in Germany. Students worked in dyads or small groups within a digital learning environment that guided them through structured phases of scientific inquiry:

1. Formulating research questions and hypotheses,
2. planning and conducting investigations,
3. analyzing and interpreting data.

The approach was the same as in Study 1. The videos (18-23 minutes, depending on condition) were paused and discussed thematically, serving as contextual and cognitive prompts to support epistemic reflection and collaborative reasoning. In addition, students engaged in epistemic scaffolding activities, which are instructional supports designed to guide learners in understanding and reflection on the reasoning behind scientific decisions. In Study 2, these activities included evaluating the clarity and testability of sample hypotheses, transforming informal questions into investigable ones, and documenting their inquiry steps. Although not all students submitted individual responses due to shared devices, all participated actively in the instructional sequence. Researchers at both locations facilitated the sessions to ensure consistency of implementation.

Immediately following the intervention, all students completed an online posttest assessing three outcome variables:

1. The perceived credibility of the scientist,
2. the perceived credibility of the research findings, and
3. the perceived tentativeness of the findings.

These dependent measures reflect core constructs derived from the study's theoretical framework and were used consistently across both studies.

4.3 Study 1

4.3.1 Participants

The final sample consisted of 148 students from Grades 10 to 12, recruited from eight classes across five secondary schools in the German state of Baden-Württemberg. Participants were between 13 and 20 years old (M = 16.33, SD = 1.11). The gender distribution was as follows: 92 female, 42 male, 2 non-binary; 12 participants did not report their gender.

4.3.2 Measures

All dependent measures were assessed using multi-item semantic differential scales. Instruments were adapted from validated tools in science communication research and aligned with the study's theoretical framework. Specifically, items were based on Flemming et al. (2020), Kimmerle et al. (2015), and the METI (Hendriks et al., 2017).

To ensure applicability to audiovisual materials, all items were rephrased in reference to the video stimulus. Students responded on five-point semantic differential scales, with higher scores indicating stronger expression of the respective construct. Example anchor descriptors included *unreliable–reliable*, *unconvincing–convincing*, and *implausible–plausible*.

4.3.2.1 Credibility of the Scientist

This construct was measured using a 9-item scale adapted from the METI. A sample item was: *"The scientist in the video seemed …" [incompetent – competent]*. The internal consistency was excellent (α = .90).

4.3.2.2 Credibility of the Research Findings

This construct was assessed with three items targeting the perceived reliability and trustworthiness of the results presented in the video. A sample item was: *"The research results presented in the video seemed …" [unconvincing – convincing]*. The internal consistency was acceptable (α = .74).

4.3.2.3 Perceived Tentativeness of the Research Findings

This scale consisted of three items evaluating whether the findings were seen as provisional, uncertain, or open to revision. A sample item was: *"The conclusions of the research seemed …" [definitive – tentative]*. The internal consistency was low (α = .51), but within acceptable bounds for exploratory research (Eisinga et al., 2013; Streiner, 2003).

To ensure methodological transparency and reduce researcher degrees of freedom, the complete study protocol (including hypotheses, experimental conditions, and analysis plans) was preregistered on AsPredicted (https://aspredicted.org/szzh-xq23.pdf).

4.3.3 Results

4.3.3.1 Descriptive Statistics

Means and standard deviations for the three dependent variables across the four experimental conditions are summarized in Table 7.

Table 7

Descriptive Statistics Across Experimental Conditions (Study 1)

Thought Process	Scientific Practice	Scientist Credibility (M/SD)	Findings Credibility (M/SD)	Tentativeness (M/SD)
Science-in-the-making	Cookbook-style	4.20 / 0.62	3.95 / 0.62	3.53 / 0.70
Science-in-the-making	Scientific reasoning style	4.11 / 0.77	4.19 / 0.65	3.47 / 0.67
Ready-made science	Cookbook-style	4.11 / 0.71	4.20 / 0.68	3.59 / 0.66
Ready-made science	Scientific reasoning style	4.23 / 0.46	4.23 / 0.64	3.71 / 0.64

4.3.3.2 Confirmatory Analyses

To test the effects of the experimental manipulations, a series of two-way between-groups ANOVAs (2 x 2 design) were conducted for each dependent variable. The factors included the scientist's thought processes (*science-in-the-making* vs. *ready-made science*), and the explanatory style of the scientific practices (*cookbook-style* vs. *scientific reasoning style*).

Across all three dependent variables (perceived credibility of the scientist, perceived credibility of the research findings, and perceived tentativeness) no significant main effects or interaction effects were found, all $Fs(1, 99) < 1.3$, n.s.

These null findings suggest that, in the given instructional context, the variations in reasoning and explanatory style did not substantially influence students' evaluations of the scientist or the scientific content.

4.3.3.3 Exploratory Analyses

To further explore relationships among the dependent variables, Kendall's tau-b (τb) correlations were computed. As shown in Table 8, perceived tentativeness of research findings was negatively correlated with both the credibility of the scientist and the credibility of the research findings. In contrast, the two credibility measures showed a positive correlation. In Table 9, the intercorrelations between the dependent variables are presented separately for each experimental group, revealing consistent patterns across conditions.

Table 8

Kendall's Tau-b Correlations (Study 1)

Variable	1	2	3
1. Perceived Tentativeness	—		
2. Credibility of the Scientist	−.32***	—	
3. Credibility of Research Findings	−.48***	.43***	—

Note. ***p < .001

Table 9

Kendall's Tau-b Intercorrelations (Study 1)

Group	Correlation: Perceived Tentativeness / Credibility of the Scientist	Correlation: Perceived Tentativeness / Credibility of the Findings	Correlation: Credibility of the Scientist / Credibility of the Findings
Science-in-the-making / Cookbook-style	−.28***	−.46***	.32***
Ready-made science / Cookbook-style	−.46***	−.50***	.55***
Science-in-the-making / Scientific reasoning style	−.32***	−.43***	.47***
Ready-made science / Scientific reasoning style	−.33***	−.59***	.48***

Note. ***p < .001

4.3.4 Discussion

Study 1 examined whether two communicative design features of science videos – scientist's thought processes (*science-in-the-making* vs. *ready-made science*) and scientific practices (*cookbook-style* vs. *scientific reasoning style*) – would influence students' perceptions of the scientist and the research presented.

Contrary to our hypotheses, the experimental manipulations produced no significant main or interaction effects on any of the three outcome variables: perceived credibility of the scientist, perceived credibility of the research findings, and perceived tentativeness. These null findings suggest that passively viewing variations in explanatory depth and epistemic transparency was probably not sufficient to alter students' perceptions in a statistically detectable way. The absence of significant effects in Study 1 may reflect the limitations of passive video formats without opportunities for epistemic engagement.

Unlike typical science communication studies that use short texts or simplified stimuli, our videos portrayed complex scientific reasoning and epistemic deliberation. Interpreting such features may require more scaffolding, especially for younger learners. Moreover, Study 1 deliberately avoided instructional framing to isolate video effects, which may have limited students' ability to engage with the epistemic content.

Prior research suggests that learners often require scaffolding to interpret uncertainty as a marker of scientific rigor rather than weakness (Flemming et al., 2020). The consistent negative correlation between tentativeness and credibility across conditions indicates that students may hold epistemic beliefs equating certainty with trustworthiness. These findings underscore the need for instructional designs that explicitly address the epistemic function of tentativeness.

Exploratory correlation analyses revealed a systematic interrelation among the dependent variables. Specifically:

- Higher perceived tentativeness of the findings was negatively associated with both the credibility of the scientist and the credibility of the findings.
- In contrast, scientist credibility and research credibility were positively associated.

These patterns indicate that students appear to apply an integrated evaluation framework: They assess the messenger (the scientist) and the message (the findings) as mutually reinforcing sources of credibility. When scientific knowledge is perceived as tentative, it may be judged as less trustworthy, perhaps reflecting common lay expectations of science as authoritative and definitive (Flemming et al., 2020; Kienhues et al., 2020; Osborne et al., 2004).

This finding raises important questions for science education. While epistemic tentativeness is a hallmark of scientific reasoning, learners may interpret such tentativeness as a signal of weakness rather than of intellectual integrity. Thus, efforts to promote epistemic understanding must also attend to students' trust frameworks and their expectations regarding scientific certainty.

The null effects observed in Study 1 also suggest possible limitations of purely observational formats. Without opportunities for active engagement or guided reflection, students may default to surface-level impressions, especially in short, classroom-based interventions. This aligns with prior critiques of passive video learning formats, which often fail to elicit deeper epistemic processing (Chinn & Malhotra, 2002; Osborne et al., 2003).

To address these limitations, Study 2 introduces a revised instructional format that integrates the same videos into a participatory learning environment, including structured reflection and application tasks. This design aligns more closely with core principles of IBL and aims to foster active epistemic engagement. In addition, the larger sample size in Study 2 enhances statistical power, enabling more robust testing of the hypothesized effects. Together, these changes aim to explore whether and how more immersive and reflective learning designs can influence students' perceptions of scientific credibility and the tentative nature of knowledge production.

4.4 Study 2

Study 2 was designed as a conceptual replication and extension of Study 1. While Study 1 tested the effects of video-based portrayals in a minimal instructional setting, Study 2 introduced a scaffolded, interactive learning environment to examine whether deeper engagement would influence students' epistemic evaluations. This two-study approach allows for a more nuanced understanding of how instructional context shapes the impact of science communication formats.

4.4.1 Participants

The second sample consisted of 607 students from Grades 10 and 11, who participated in the study as part of 41 school classes from two German federal states. The classes had voluntarily signed up for the project. Participants ranged in age from 13 to 20 years (M = 16.49, SD = 1.13). Of the total sample, 324 students identified as female, 231 as male, and 13 as non-binary; 39 students intentionally chose not to disclose their gender, and gender information was missing for 12 students.

4.4.2 Measures

As in Study 1, all dependent variables were assessed using multi-item semantic differential scales (5-point format), with higher values indicating stronger endorsement of the respective construct.

4.4.2.1 Credibility of the Scientist

Assessed using a 9-item version of the METI (Hendriks et al., 2017). A sample item reads: *"The scientist in the video appeared …"* (*incompetent – competent*). Internal consistency was excellent (α = .90).

4.4.2.2 Credibility of the Research Findings

Measured with three items evaluating the plausibility and reliability of the presented results (e.g., *unconvincing – convincing*). Internal consistency was acceptable (α = .77).

4.4.2.3 Perceived Tentativeness of the Research Findings

Assessed using three items addressing the perceived provisionality of the conclusions (e.g., *final – tentative*). Internal consistency was relatively low (α = .54), but comparable to that obtained in Study 1 and acceptable for exploratory research (Eisinga et al., 2013; Streiner, 2003). The same scale was retained across studies to ensure methodological consistency and comparability. Although no validated instrument currently exists to measure perceptions of scientific tentativeness in educational or public contexts, employing the same items allows for exploratory insights and cross-study comparability within this emerging research area.

4.4.2 Results

4.4.2.1 Descriptive Statistics

Table 10 shows the means and standard deviations for all dependent variables across the four experimental conditions.

Table 10

Descriptive Statistics Across Experimental Conditions (Study 2)

Thought Process	Scientific Practice	Scientist Credibility (*M*/*SD*)	Findings Credibility (*M*/*SD*)	Tentativeness (*M*/*SD*)
Science-in-the-making	Cookbook-style	4.31 / 0.55	4.19 / 0.64	2.30 / 0.56
Science-in-the-making	Scientific reasoning style	4.27 / 0.60	4.24 / 0.62	2.32 / 0.58
Ready-made science	Cookbook-style	4.36 / 0.59	4.28 / 0.65	2.16 / 0.63
Ready-made science	Scientific reasoning style	4.28 / 0.70	4.16 / 0.79	2.22 / 0.70

4.4.2.2 Confirmatory Analyses

To examine the effects of the scientist's thought processes (*science-in-the-making* vs. *ready-made science*) and the scientific practices (*cookbook-style* vs. *scientific reasoning style*) on students' perceptions, a series of two-way between-groups ANOVAs was conducted for each dependent variable.

Credibility of the Scientist. No significant main effects or interaction were found, all Fs(1, 603) < 1.7, *n.s.* The visibility of the scientist's reasoning or the inclusion of explanatory narration did not significantly alter how credible the scientist was perceived to be.

Credibility of the Research Findings. Similarly, the perceived credibility of the research findings remained unaffected across conditions, all Fs(1, 603) < 2.5, *n.s.* Students' credibility perceptions of the research findings were not significantly influenced by the scientist's thought processes or the mode of scientific practices.

Perceived Tentativeness of the Research Findings. A significant main effect emerged for the mode of presenting the scientist's thought processes, $F(1, 603) = 5.65$, $p = .018$, $\eta^2 = .009$. Students exposed to the *science-in-the-making* condition perceived the findings as more tentative ($M = 2.31$, $SE = 0.05$) than those in the *ready-made science* condition ($M = 2.19$, $SE = 0.05$), with a Bonferroni-adjusted $p = .018$.

This finding supports the idea that explicitly communicating the scientist's reasoning – including moments of uncertainty – helps students recognize the provisional nature of scientific knowledge.

There was neither a significant main effect for the scientific practices, $F(1, 603) = 0.70$, $p = .403$, nor an interaction effect, $F(1, 603) = 0.10$, $p = .758$. Pairwise post-hoc comparisons between all interaction conditions confirmed this pattern (*all* $p\_adj > .14$).

4.4.2.3 Exploratory Analyses

To explore the relationships between the key dependent variables, Kendall's tau-b (τb) correlations were calculated. As shown in Table 11, perceived tentativeness of the research findings was negatively correlated with both the credibility of the scientist and the credibility of the research findings. Conversely, a positive correlation was observed between the credibility of the scientist and that of the research findings. These correlations were further examined separately by condition (see Table 12), revealing consistent patterns across groups, with negative associations between perceived tentativeness and both credibility measures, and a positive association between the two credibility measures.

Table 11

Kendall's Tau-b Correlations (Study 2)

Variable	1	2	3
1. Perceived Tentativeness	—		
2. Credibility of the Scientist	−.33***	—	
3. Credibility of Research Findings	−.46***	.47***	—

Note. ***$p < .001$

Table 12

Kendall's Tau-b Intercorrelations (Study 2)

Group	Correlation: Perceived Tentativeness / Credibility of the Scientist	Correlation: Perceived Tentativeness / Credibility of the Findings	Correlation: Credibility of the Scientist / Credibility of the Findings
Science-in-the-making / Cookbook-style	−.26***	−.37***	.48***
Ready-made science / Cookbook-style	−.36***	−.45***	.48***
Science-in-the-making / Scientific reasoning style	−.29***	−.48***	.43***
Ready-made science / Scientific reasoning style	−. 43***	−.56***	.51***

Note. ***p < .001

4.4.3 Discussion

Study 2 replicated and extended the findings of Study 1 by implementing a larger sample and a scaffolded interactive instructional format. Consistent with Study 1, no significant effects were found for the portrayal of scientists' thought processes (*science-in-the-making* vs. *ready-made science*) or the presentation of scientific practices (*cookbook-style* vs. *scientific reasoning style*) on students' perceptions of the credibility of the scientist or the credibility of the research findings.

A central difference, however, emerged in students' perceptions of the tentativeness of scientific findings. In Study 2, a significant main effect was found for the mode of presenting scientist's thought processes: Participants exposed to *science-in-the-making* rated the findings as more tentative than those who viewed a *ready-made science* portrayal. This suggests that when students are given insight into the scientist's reasoning – including expressions of uncertainty and contextual justification – they are more likely to recognize the provisional nature of scientific knowledge. As this effect was not part of our preregistered hypotheses, it should be interpreted as exploratory. Nonetheless, it provides valuable insight into how epistemic transparency may foster students' awareness of scientific tentativeness.

This effect was not observed in Study 1, which lacked the reflective and interactive components implemented in Study 2. The structured learning environment, including opportunities for discussion, epistemic prompts, and scaffolded reflection, may have allowed students to engage more deeply with the epistemic features of the material. These results emphasize the importance of instructional context in supporting students' epistemic sensitivity, that is, the ability to notice, interpret, and respond to indicators of how knowledge is constructed, justified, and revised.

Interestingly, overall ratings of perceived tentativeness were lower in Study 2 than in Study 1, despite the more elaborate instructional design. This may reflect procedural differences: the full-day format with collaborative tasks and structured guidance may have encouraged students to focus on coherence and resolution rather than on epistemic ambiguity. Future research should examine how instructional pacing and task framing influence students' sensitivity to scientific tentativeness.

Importantly, the inclusion of *science-in-the-making* thought processes did not reduce the perceived credibility of the scientist or the research findings. This replicates the null effects found in Study 1 and suggests that making uncertainty and reasoning visible does not inherently undermine trust, especially when embedded in a learning environment that supports reflection and critical thinking. One possible explanation is that our manipulations focused on epistemic features of the communication rather than on personal characteristics of the scientist. Since the scientist's demeanor, tone, and role remained constant across all conditions, students may have formed credibility judgments based on these stable cues rather than on the structure of the scientific narrative.

Overall, these findings highlight the potential of using *science-in-the-making* portrayals to foster a more nuanced understanding of the tentative and evolving nature of scientific knowledge. Making scientist's thought processes visible may support epistemic growth, enabling students to critically engage with how knowledge is constructed, evaluated, and communicated.

4.5 General Discussion

This research investigated how video-based educational tools that authentically depict scientific inquiry can influence students' understanding of the nature if science. Rather than merely conveying scientific facts, the videos aimed to make visible how knowledge is generated, interpreted, and revised over time. The focus lay on two core dimensions of science communication: the portrayal of scientists' thought processes (*science-in-the-making* vs. *ready-made science*) and the presentation of scientific practices (*cookbook-style* vs. *scientific reasoning style*). Across two school-based field experiments, we examined how these variations influenced students' perceptions of the credibility and tentativeness of scientific findings.

Across both studies, no significant effects were found on credibility perceptions, neither for the scientist nor for the research findings. However, in Study 2, participants rated findings as significantly more tentative when the scientist's thought processes were presented in a *science-in-the-making* style. This suggests that the visibility of uncertainty and epistemic deliberation – when embedded in a structured, reflective learning context – can enhance students' awareness of the provisional nature of scientific knowledge.

Notably, the experimental manipulations did not systematically alter the portrayal of the scientist as a person, but rather the visibility of their epistemic reasoning. This may explain the absence of effects on credibility judgments: Although we assessed perceived credibility of the researcher, students may have based their evaluations on relatively stable cues such as professionalism or communication style, which remained constant across conditions. In this sense, the study did not manipulate who the scientist was perceived to be, but rather how their reasoning was made visible.

4.5.1 Theoretical Implications

The significant correlation patterns observed in both studies revealed a consistent epistemic logic: Perceived tentativeness was negatively associated with credibility, while judgments about the scientist and their findings were positively aligned. This finding mirrors previous results in science education and communication research, where tentativeness is often misunderstood as a lack of knowledge or confidence rather than a marker of epistemic caution and methodological rigor (Flemming et al., 2020; Osborne et al., 2004; Thomas et al., 2025). Students frequently hold epistemic beliefs that equate scientific validity with certainty – a pattern that may reflect not only misconceptions, but also a lack of exposure to the epistemic norms of scientific reasoning (Fiske & Dupree, 2014; Hofer & Pintrich, 1997; Iordanou, 2016; van der Bles et al., 2020).

At the same time, the observed alignment between judgments of the scientist's credibility and the credibility of their findings – although conceptually distinct –

highlights a critical nuance. As Mason et al. (2014) argue, audiences form credibility judgments by evaluating both source trustworthiness and message plausibility, which interact in subtle ways. This suggests that educational interventions should systematically support learners in evaluating not only what is being said, but also who is saying it – and why.

The fact that students were more likely to recognize the tentative nature of scientific findings when *science-in-the-making* portrayals were paired with explanatory narration supports earlier findings that uncertainty is best understood when embedded in a coherent epistemic context (Kimmerle et al., 2015). Although the interaction was not statistically significant, the main effect of narration suggests that narrative coherence and epistemic scaffolding are crucial for fostering productive interpretations of scientific tentativeness.

4.5.2 Limitations and Future Research

Several limitations of this research should be acknowledged. First, the internal consistency of the scale measuring perceived tentativeness was modest in both studies. While still acceptable for exploratory research (Eisinga et al., 2013; Streiner, 2003), this limits interpretability at the item level. Future work should aim to refine this instrument by expanding the item pool to more fully reflect the multidimensional nature of tentativeness in scientific reasoning, including aspects such as epistemic uncertainty, openness to revision, and the provisional status of claims. Complementary qualitative or mixed-methods approaches may also help uncover how students interpret and express tentativeness in authentic learning contexts.

Second, the correlational findings, though theoretically coherent and replicable, do not permit causal conclusions. While our experimental design isolated the effects of different modes of presenting scientist's thought processes and scientific practices, the correlational links between perceived tentativeness and credibility may be shaped by unobserved factors, such as pre-existing epistemic beliefs or domain knowledge. Future experimental research could more directly manipulate uncertainty expressions and assess their causal impact on epistemic outcomes.

Third, the interventions were situated within school contexts and designed around a specific ecological research case. It remains to be examined whether these findings generalize to science topics that carry higher emotional or societal relevance, such as climate change or public health. In such contexts, trust in science may be shaped by personal identity, risk perception, and media framing – factors that go beyond instructional design.

Fourth, we did not assess students' prior knowledge about bats. While the videos were designed to be self-contained and accessible to all students, variation in prior domain knowledge may have influenced how students interpreted the research process and evaluated its credibility. Future studies should consider including pre-assessments to account for such individual differences.

Fifth, our study relied exclusively on quantitative survey data. While this approach allowed for standardized measurement across a large sample, it limited our ability to capture deeper insights into students' learning processes. We did not include qualitative methods such as interviews, classroom observations, or think-aloud protocols. Future research should incorporate such methods to enable triangulation and to better understand how students engage with scientific reasoning and epistemic uncertainty.

Sixth, we did not assess students' prior conceptions of the nature of science or their epistemological beliefs. These individual differences likely influenced how students interpreted the video content and responded to the survey items. Without accounting for such mediating variables, our findings must be interpreted with caution. Future studies should include pre-assessments or qualitative methods to explore how learners' existing views shape their engagement with instructional representations of scientific reasoning.

Despite these limitations, the study contributes several notable strengths. First, the two studies were implemented across distinct instructional formats (one minimal and one scaffolded), enhancing ecological validity and allowing for meaningful comparison of engagement effects. Second, the video materials were theory-informed, grounded in an eight-phase model of scientific inquiry, and aligned with competence-oriented science education frameworks. This ensured that scientific practices were not only presented procedurally but also framed epistemically, reflecting the deductive-inductive character of real-world scientific reasoning. Third, the integration of authentic research content, epistemic scaffolding, and digital delivery represents a contemporary approach to bridging science communication and science education.

4.5.3 Implications for Science Education

The findings offer several important implications for science education.

First, our findings suggest that students may be capable of recognizing the tentative nature of scientific knowledge, particularly when scientific thought processes are presented in a *science-in-the-making* mode. However, this interpretation should be treated with caution, as the analyses were exploratory and the internal consistency of the tentativeness scale was modest. When the reasoning behind scientific decisions is made visible and framed through explanation, learners appear more sensitive to the provisional, interpretive, and evolving nature of scientific inquiry. This underscores the value of epistemic transparency and the role of instructional design in fostering epistemic sensitivity. Educators should not only emphasize what was done in a scientific study, but also why it was done and how methodological decisions were justified.

Interestingly, the overall level of perceived tentativeness was lower in Study 2 than in Study 1, despite the more elaborate instructional design. This may reflect procedural differences: Study 2 involved collaborative tasks and structured guidance, which may have shifted students' focus toward coherence and resolution rather than epistemic ambiguity. Alternatively, the extended format may have led to cognitive saturation or reduced sensitivity to uncertainty cues. These possibilities warrant further investigation.

Second, while portrayals of *science-in-the-making* did not reduce credibility in this study, such outcomes may not generalize across settings. Students' interpretation of uncertainty depends on their prior beliefs about science, their level of trust in institutional knowledge, and the salience of the topic. Science education should therefore explicitly address the epistemic function of tentativeness – not as a deficit, but as a hallmark of scientific rigor. This may involve comparing different modes of communicating uncertainty and reflecting on how these modes relate to norms of scientific reasoning and discourse.

Third, the conceptual distinction between scientific thought processes and scientific practices appear to be useful in both theory and application. Our findings suggest that simply illustrating procedural steps (as is typical of *cookbook-style* instructions) may not suffice to alter students' perceptions of science. Instead, it is the epistemic framing of these steps (consistent with *scientific reasoning style*) that allows students to engage with scientific inquiry as a reasoned, reflective, and evidence-based process. Instructional tools should therefore integrate representations of *science-in-the-making* with clear rationales behind research actions to encourage students' critical engagement with the logic of inquiry.

Finally, our results reinforce the need to distinguish between credibility of the source (the scientist) and credibility of the content (the research findings). Although the two were positively correlated, they remain analytically distinct and may respond differently to instructional manipulations. Building on findings by Mason et al. (2014), future research and instructional design should pay closer attention to how learners form these judgments and how they interact with developing epistemic beliefs.

4.6 Conclusion

Building on these implications for science education, the findings from both studies highlight a key interpretive tension: Students must navigate science as both credible and tentative. Educational portrayals that emphasize *science-in-the-making* can support learners in viewing science not as a body of static facts, but as a dynamic, evolving, and interpretive process of knowledge construction. However, these portrayals may challenge learners' expectations of scientific certainty and therefore require careful scaffolding.

To advance scientific literacy, education must support learners in reconciling scientific credibility with revisability. Scientific knowledge is not weakened by its tentativeness; rather, it is strengthened by transparency, methodological rigor, and its capacity for self-correction. Helping students understand this requires not only showing *what* scientists do but also making visible *how* and *why* they do it.

Transition to Chapter 5

While Chapters 3 and 4 explored perceptions of tentativeness and credibility in students across controlled and classroom contexts, it remained an open question how the findings generalize to the broader public. Chapter 5, "Understanding Scientific Tentativeness Through Bat Ecology: A Video-Based Study to Promote Scientific Literacy in Wildlife Research" addresses this gap by examining a large, diverse general population sample using the German bat ecology case.

This chapter applies the same research process presentations and manipulations established in the previous studies, allowing for a systematic test of robustness and reliability across audiences, contexts, and materials. By extending the investigation beyond educational settings, Chapter 5 integrates the cumulative insights of the dissertation and highlights the broader implications for science communication, public trust, and the promotion of scientific literacy.

5. Understanding Scientific Tentativeness Through Bat Ecology: A Video-Based Study to Promote Scientific Literacy in Wildlife Research

Statement of Contribution

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Vanessa van den Bogaert	3	-	-	-	2
Hannah Greving	4	-	-	-	1
Till Bruckermann	5	-	-	-	5
Anke Schumann	6	-	-	-	1
Miriam Brandt	7	-	-	-	1
Carolin Scholz	8	-			1
Daniel Lewanzik	9	-	-	-	1
Christian C. Voigt	10	-	-	-	1
Ute Harms	11	-			1
Joachim Wirth	12	-			1
Joachim Kimmerle	13	20	-	-	10
Title of Paper	Understanding Scientific Tentativeness Through Bat Ecology: A Video-Based Study to Promote Scientific Literacy in Wildlife Research				
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Abstract

This study investigates how different video-based representations of scientific practice and a scientist's thought processes influence public perceptions of credibility, both of the scientist and the research, as well as perceived tentativeness of scientific findings and academic self-efficacy. In an experimental online study with a German general population sample ($N = 1{,}105$), four videos depicting bat ecology fieldwork were tested. The videos varied in two factors: representation of scientific practices (*cookbook-style* vs. *scientific reasoning style*) and portrayal of the scientist's thought processes (*science-in-the-making* vs. *ready-made science*). Results show that more elaborated representations, especially those reflecting *styles of scientific reasoning* and *science-in-the-making*, led to higher perceptions of tentativeness. These findings underscore the importance of transparently communicating the epistemic process of scientific knowledge construction to foster scientific literacy. Bat ecology, with nocturnal behavior, complex habitats, and conservation challenges, offers a compelling context for examining communication of uncertainty.
Keywords: bat ecology, science communication, tentativeness, credibility, scientific literacy, nature of science

5.1 Introduction

In an era of widespread misinformation, fostering scientific judgement and the ability to engage with uncertainty has become increasingly vital. Science communication is undergoing a paradigm shift – from the mere dissemination of results toward a more transparent portrayal of how scientific knowledge is generated. A key challenge in this transformation lies in conveying epistemic features – such as uncertainty, tentativeness, and the revisability of knowledge – not as flaws, but as essential attributes of scientific inquiry. Wildlife research, and bat ecology in particular, exemplifies this epistemic complexity (Greving et al., 2022). Wildlife fieldwork often unfolds under unpredictable conditions, requiring adaptive methodologies and interpretative reasoning (Thomas et al., 2025). These characteristics make bat research a compelling domain for exploring how the public perceives scientific tentativeness and credibility.

Visually engaging formats, especially video, offer promising ways to communicate epistemic dimensions. Digital media enables more direct, multimodal, and participatory forms of public science communication (Peters et al., 2014). Video combines visual, auditory, and narrative elements to create immersive experiences that support cognitive and emotional engagement (Eitel & Scheiter, 2015; Mayer, 2020). These affordances make video particularly well-suited to conveying the iterative and uncertain nature of scientific practices.

Recent scholarship emphasizes that understanding the nature of science must extend beyond methods and content to include how science is communicated publicly. Public understanding of science depends not only on grasping how knowledge is produced, but also on evaluating the credibility of scientific claims and perceiving one's own ability to engage with scientific information (Höttecke & Allchin, 2020). In the context of science communication, these psychological constructs – play a central role in shaping how audiences interpret scientific messages and respond to uncertainty.

Against this backdrop, the study presented here investigated how different representations of scientist's thought processes, *science-in-the-making* versus *ready-made science*, and varying degrees of explanatory detail (*cookbook-style* vs. *scientific reasoning style*) affect the epistemic processing of non-expert audiences. Drawing on Latour and Woolgar's (1986, 2013) distinction between finalized and provisional science, as well as on recent research in epistemic cognition and public trust (Höttecke & Allchin, 2020; Schneider et al., 2022), the study examines how these representations influence viewers' perceptions of tentativeness, credibility (of both the scientist and the research), and their own scientific self-efficacy. The intervention is situated in the context of bat ecology fieldwork and uses videos to simulate authentic scientific practice.

5.1.1 Theoretical Framework

Scientific communication styles influence how audiences perceive credibility, tentativeness, and their own capacity to engage with scientific information (Flemming et al., 2020). The present study examines two key dimensions of such styles: (1) the portrayal of the scientist's thought process – *science-in-the-making* versus *ready-made science* (Latour & WooIgar, 1986, 2013) – and (2) the presentation of the research process – *cookbook-style* versus *scientific reasoning style* (Kind & Osborne, 2017). Both dimensions have roots in scholarship on the nature of science, epistemic cognition, and the human dimensions of wildlife research, and both can profoundly shape public engagement with scientific content (Matthews, 2006).

5.1.1.1 Science-in-the-Making versus Ready-Made Science

Latour and Woolgar's (1986, 2013) conceptual distinction between *science-in-the-making* and *ready-made science* offers a valuable lens for understanding how scientific knowledge is produced and perceived. *Ready-made science* presents findings as fixed and authoritative, often concealing the uncertainties, negotiations, and contextual decisions that shape them. In contrast, *science-in-the-making* highlights the provisional, adaptive, and socially embedded nature of scientific inquiry, revealing the iterative and negotiated aspects of knowledge production.

In wildlife research – particularly in field-based disciplines such as bat ecology – scientists frequently adapt their data collection methods in response to shifting environmental conditions or unexpected animal behavior. These real-time decisions exemplify *science-in-the-making* and present opportunities to engage the public with the realities of ecological research. Educational and outreach efforts that highlight such processes can foster a more nuanced understanding of wildlife science – one that values transparency, adaptability, and epistemic humility.

At the same time, there is a communicative trade-off: while *ready-made science* can convey authority and clarity, it risks concealing the epistemic labor behind research (Latour & Woolgar, 1986, 2013). Recent analyses reveal hidden divisions of labor in scientific writing, showing how many contributions remain invisible in the final published work (Pei et al., 2025). Such invisibility can influence science communication by shaping whose voices, perspectives, and reasoning processes become publicly visible – potentially affecting perceived credibility, inclusiveness, and the transparency of research. These findings reinforce the argument that finalized science often masks its social and iterative character, where *science-in-the-making* invites audiences to witness the construction and revision of knowledge, thereby deepening epistemic engagement and promoting scientific literacy grounded in humility and critical reflection.

5.1.1.2 Cookbook-Style versus Scientific Reasoning Style in Wildlife Research

The second dimension concerns how the research process itself is presented. A *cookbook-style* format depicts procedures as a linear, step-by-step recipe, emphasizing procedural clarity and replicability but omitting the underlying reasoning, decision-making, and uncertainties (Domin, 1999; Kirschner et al., 2006). In this way, *cookbook-style* communication parallels *ready-made science* by framing research as a fixed and mechanical activity. In science communication and education, framing research as a mechanical activity (i.e., the scientific method) could foster misconceptions of the nature of scientific inquiry (Woodcock, 2014).

By contrast, the *scientific reasoning style* makes explicit the cognitive and epistemic processes underlying research decisions, such as weighing evidence, adapting methods to new conditions, or revising hypotheses (Kind & Osborne, 2017; Kuhn, 1999; Zimmerman, 2000). Unlike *science-in-the-making*, which emphasizes the emergent and interpretative nature of knowledge, the *scientific reasoning style* focuses on communicating the procedural and epistemic knowledge inherent in scientific practice.

In the human dimensions of wildlife research, recognizing and communicating these reasoning styles is especially relevant. Field studies in areas such as bat ecology often involve unpredictable weather, habitat variability, and complex animal behaviors that require ongoing methodological adjustments (Decker et al., 2012). Transparently presenting such reasoning not only conveys authenticity but can also foster public trust by showing the care and rigor behind scientific conclusions (Düsing et al., 2025).

Understanding these contrasting presentation styles is essential for examining how they influence perceptions of credibility and tentativeness – core dimensions of science communication that aim to foster epistemic literacy.

5.1.1.3 Communicating Epistemic Principles

Research in epistemic cognition highlights the importance of communicating uncertainty, tentativeness, and revisability of knowledge (Furtak et al., 2012; Lombardi et al., 2016). These principles help people navigate complex socio-scientific issues.

However, making epistemic complexity visible poses a dilemma: Transparency can enhance understanding and trust among engaged audiences, but tentativeness may be misinterpreted as incompetence or indecisiveness (Flemming et al., 2020; Scharrer et al., 2017; Thomas et al., 2025).

5.1.1.4 Presentation Style, Researcher Portrayal, and Video Formats

Video-based formats offer a promising solution to this dilemma. Their multimodal nature allows abstract epistemic concepts to be conveyed in accessible and emotionally resonant ways (Eitel & Scheiter, 2015; Mayer, 2020). Explanatory formats that reveal reasoning and decision-making processes have been shown to enhance comprehension and trust (Mayer, 2024; Noetel et al., 2021). Portraying scientists engaged in authentic problem-solving rather than simply presenting polished conclusions can stimulate epistemic cognition and strengthen scientific self-efficacy (Hannula et al., 2022; Lombardi et al., 2016). The portrayal of scientists also plays a key role. While *ready-made science* emphasizes authority, *science-in-the-making* presents scientists as relatable individuals navigating uncertainty (Hendriks et al., 2016b; Hendriks & Jucks, 2020). This can enhance transparency and engagement but must be carefully designed to avoid undermining trust (Castro-Meneses et al., 2020).

5.1.1.5 Academic Self-Efficacy and Epistemic Processing

Academic self-efficacy – individuals' belief in their ability to engage with complex content (Giere, 1997) – influences how people process scientific information. Those with higher self-efficacy tolerate ambiguity more readily, engage in reflective thinking, and appreciate the provisional nature of scientific knowledge (Hannula et al., 2022). Such individuals may respond more positively to portrayals of *science-in-the-making*, seeing uncertainty as a natural part of scientific inquiry, while those with lower self-efficacy may prefer more definitive narratives. Recognizing these differences is crucial for designing inclusive and epistemically rich science communication, particularly in fields like wildlife research where uncertainty is inherent.

5.1.2 Research Hypotheses

Drawing on the theoretical framework outlined above, our study examines how different communication styles and individual differences shape perceptions of credibility and tentativeness in wildlife research. Prior research suggests that the way scientific information is presented can influence both the perceived credibility of the scientist and of the research findings, as well as how tentative audiences consider scientific knowledge to be (Flemming et al., 2020; Kind & Osborne, 2017; Latour & Woolgar, 1986, 2013).

5.1.2.1 Portrayal of Scientists and Credibility

Ready-made science presents scientific knowledge as finalized and authoritative, emphasizing expertise and certainty. In contrast, *science-in-the-making* highlights the iterative, provisional, and socially embedded nature of research (Latour & Woolgar, 1986, 2013). Students often value authority, enhancing credibility when scientists appear knowledgeable (Flemming et al., 2020; Kind & Osborne, 2017). Similar tendencies are observed in adult populations, where trust in science is linked to perceptions of competence and authority (Wissenschaft im Dialog, 2024).

5.1.2.2 Presentation of Research Processes

The way research is communicated, either as a *cookbook-style* procedure or through *scientific reasoning style*, can influence perceptions of credibility and perceived tentativeness. *Cookbook-style* presentations emphasize procedural clarity and replicability but obscure the reasoning behind decisions, potentially leading audiences to view findings as fixed and limiting their appreciation of uncertainty (Domin, 1999; Kirschner et al., 2006). In contrast, the *scientific reasoning style* makes decision-making explicit, highlighting adaptive strategies and evidentiary reasoning. This approach fosters recognition of uncertainty and tentativeness while enhancing credibility by demonstrating rigor and transparency (Kind & Osborne, 2017; Kuhn, 1999; Scharrer et al., 2017).

5.1.2.3 Individual Differences in Academic Self-Efficacy

Academic self-efficacy refers to individuals' beliefs in their capability to achieve academic goals (Artino, 2012; Pajares, 1996). It influences engagement with complex content: those with higher self-efficacy tolerate ambiguity, engage in reflective reasoning, and appreciate the provisional nature of scientific knowledge (Hannula et al., 2022). The relationship with credibility is nuanced: high self-efficacy could reduce credibility if certainty is valued or increase it if audiences identify with scientists' reasoning processes.

5.1.2.4 Hypotheses

Drawing on these considerations, the study tests the following preregistered hypotheses (AsPredicted: https://aspredicted.org/r5hw-vzhh.pdf):

H1: A *ready-made science* portrayal of the scientist will lead to higher perceived credibility of the scientist compared to a *science-in-the-making* portrayal.

H2: Presenting the research process through a *scientific reasoning style* will lead to higher perceived credibility of the research findings than presenting the process in a *cookbook-style* format.

H3: Presenting the research process through a *scientific reasoning style* will lead to higher perceived tentativeness of the findings than presenting the process in a *cookbook-style* format.

H4: Academic self-efficacy will be positively associated with perceived tentativeness.

H5: Academic self-efficacy will be negatively correlated with credibility ratings (of both the scientist and the research findings).

H6: Perceived tentativeness will be negatively correlated with credibility ratings.

5.2 Method

5.2.1 Study Design and Sample

The online video experiment was conducted in December 2024 via the platform *Prolific*, targeting a general German-speaking population. A total of N = 1,107 individuals completed the study. However, two participants subsequently withdrew their data, resulting in a final sample of N = 1,105 for analysis. Participants ranged in age from 18 to 74 years (M = 31.89, SD = 10.14). The sample comprised 645 men, 439 women, and 17 individuals identifying as diverse. Participants also represented a broad range of educational backgrounds and academic disciplines. The video topic of bat research was chosen not only for its ecological relevance but also because it exemplifies the iterative and uncertain nature of field-based scientific inquiry.

5.2.2 Experimental Design

A 2×2 between-groups factorial design was employed to examine the impact of science communication strategies on public perceptions of scientific credibility and the tentativeness of scientific findings. Participants were randomly assigned to one of four experimental conditions resulting from the combination of two independent variables: the presentation of scientific practices (*cookbook-style* vs. *scientific reasoning style*) and the portrayal of the scientist's thought processes (*science-in-the-making* vs. *ready-made science*).

All participants viewed a video on bat research conducted in Germany. The featured research focused on the effects of artificial light at night (ALAN) on the commuting behavior of the Greater Mouse-eared bat (*Myotis myotis*), a widespread species in Central Europe that often roosts in the attics of large buildings in towns and villages. To reach rural foraging areas, these bats typically commute over long distances after dusk. In the original field study, seventy adult females from three differently sized settlements in Germany were equipped with miniature GPS loggers, allowing for the collection of high-resolution spatial and temporal movement data. The research examined how ALAN, particularly street lighting, and other landscape features, such as water bodies, vegetation, and sealed surfaces, influenced route choice.

Results showed that Greater Mouse-eared bats clearly avoided illuminated areas and instead preferred dark corridors, often near water, as reported in a manuscript currently under review by Lewanzik et al. (2025).

The videos used in the present study were equivalent in core content but systematically varied along the two manipulated dimensions (Düsing et al., 2025). The study aimed (a) to authentically represent field-based scientific research on bat ecology for a lay audience and (b) to assess which combinations of communication styles most effectively enhance public understanding of scientific reasoning and promote trust in science. This design enabled a nuanced analysis of how distinct facets of science communication jointly shape audience perceptions.

5.2.3 Measures

The study assessed three primary dependent variables: (a) perceived credibility of the scientist, (b) perceived credibility of the research findings, and (c) perceived tentativeness of the findings. In addition, academic self-efficacy was measured as a predictor variable to examine its associations with perceived tentativeness and credibility ratings (Hypotheses 4 and 5). After viewing the video, participants completed a series of established and validated questionnaires.

5.2.3.1 Perceived Credibility of the Scientist

Perceived credibility of the scientist was assessed using the 14-item *Epistemic Trustworthiness Inventory* (Hendriks et al., 2017) rated on 7-point semantic differential scales (e.g., *competent–incompetent*, *honest–dishonest*). The scale showed excellent internal consistency (Cronbach's α = .93 (standardized α = .93). Additional reliability indices included Guttman's $\lambda 6$ = .95, an average inter-item correlation of r = .50, and a signal-to-noise ratio of 14.00.

5.2.3.2 Perceived Credibility of the Research Findings

Perceived credibility of the research findings was measured with a 5-item scale using 7-point semantic differential items (e.g., *credible–noncredible*, *reliable–unreliable*). The scale showed excellent internal consistency, with Cronbach's α = .91 (standardized α = .91). Guttman's $\lambda 6$ was .89, the average inter-item correlation was r = .67, and the signal-to-noise ratio was 10.00.

5.2.3.3 Perceived Tentativeness of the Research Findings

Perceived tentativeness of the findings was measured with the six-item *Perceived Tentativeness Scale* (Flemming et al., 2020), rated on a 7-point Likert scale (e.g., "*The study is conclusive*" [reverse-coded]). In the present experimental context, the internal consistency was modest, with Cronbach's α = .54 (standardized α = .55). Additional reliability indices included Guttman's $\lambda 6$ = .58, an average inter-item correlation of r = .17, and a signal-to-noise ratio of 1.20. While these values are lower than typically recommended for applied surveys, reliabilities in short scales under experimental conditions – particularly when measuring abstract constructs – are often in this range and considered acceptable for research response (Cortina, 1993; Streiner, 2003).

5.2.3.4 Academic Self-Efficacy

Academic self-efficacy was assessed with four items on a 5-point Likert scale (e.g., "*I am usually able to understand scientific content*"). The internal consistency of the scale was acceptable, with Cronbach's α = .77 (standardized α = .70). Additional reliability indices included Guttman's $\lambda 6$ = .65, an average inter-item correlation of r = .32, and a signal-to-noise ratio of 2.30, indicating a moderate degree of internal reliability.

5.2.4 Procedure and Exclusion Criteria

Participants were excluded if they (a) discontinued the study, (b) frequently left the video tab, or (c) failed an attention check (e.g., identifying the bat species). Two additional participants withdrew their data in line with ethical guidelines. The participants included were at least 18 years old, passed the attention check, and gave written informed consent.

5.2.5 Sample Size Determination and Randomization

An a priori power analysis using G*Power (α = .05, power = .80) indicated a required sample of N = 1,095 to detect a small interaction effect (η^2 = .01) in a two-way ANOVA with a 2×2 factorial design, corresponding to approximately n = 273 per condition. We collected data from online participants via the platform *Prolific*, where all participants were randomly assigned to one of four video conditions: *science-in-the-making* x *cookbook-style* (n = 276), *science-in-the-making* x *scientific reasoning style* (n = 276), *ready-made science* x *cookbook-style* (n = 275), *ready-made science* x *scientific reasoning style* (n = 278).

5.3 Results

5.3.1 Perceived Credibility of the Scientist (H1)

A two-way ANOVA examined the effects of scientist portrayal (*science-in-the-making* vs. *ready-made science*) and presentation style (*cookbook-style* vs. *scientific reasoning style*) on the perceived credibility of the scientist. There were no significant main effects of portrayal, $F(1, 1{,}101) = 2.61$, $p = .106$, or presentation style, $F(1, 1{,}101) = 0.12$, $p = .726$. The interaction between portrayal and presentation was also not significant, $F(1, 1{,}101) = 0.15$, $p = .702$.

5.3.2 Perceived Credibility of the Research Findings (H2)

A second two-way ANOVA examined the same independent variables with perceived credibility of the research findings as the outcome. Again, no significant main effects were observed for portrayal, $F(1, 1{,}101) = 0.00$, $p = .954$, or presentation style, $F(1, 1{,}101) = 0.98$, $p = .324$. The interaction was not significant either, $F(1, 1{,}101) = 0.58$, $p = .446$.

5.3.3 Perceived Tentativeness of the Research Findings (H3)

Hypothesis 3 predicted that presenting the research process through *scientific reasoning style* would increase perceived tentativeness compared to a *cookbook-style* presentation. A two-way ANOVA revealed significant main effects for both the scientist's portrayal, $F(1, 1{,}101) = 14.10$, $p < .001$, $\eta^2 = .01$, and the presentation style, $F(1, 1{,}101) = 684.02$, $p < .001$, $\eta^2 = .38$. The interaction between the two factors was not significant, $F(1, 1{,}101) = 1.70$, $p = .192$.

Pairwise comparisons for the main effects showed that participants rated findings as more tentative in the scientific reasoning conditions ($M = 4.45$, $SD = 0.68$) than in the *cookbook-style* conditions ($M = 3.48$, $SD = 0.54$). Likewise, findings were perceived as more tentative in the *science-in-the-making* conditions ($M = 4.03$, $SD = 0.61$) compared to the *ready-made science* conditions ($M = 3.89$, $SD = 0.61$). These results support H3 and demonstrate that the style of presentation, particularly scientific reasoning, has a substantial impact on perceived tentativeness, independent of whether the research is framed as *science-in-the-making* or *ready-made science* (see Figure 2).

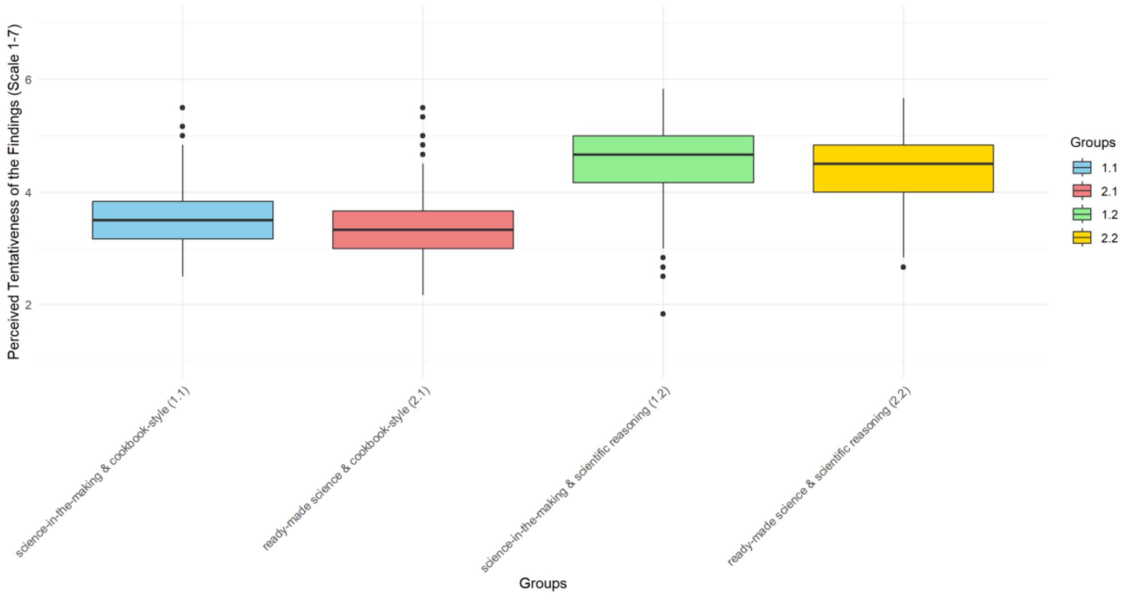

Figure 2

Boxplot of the Perceived Tentativeness of the Research Findings

5.3.4 Academic Self-Efficacy and its Predictive Role (H4–H5)

Hypothesis 4 predicted a positive correlation between academic self-efficacy and perceived tentativeness, which was not supported, $r = .03$, $p = .354$. Hypothesis 5 posited a negative association between academic self-efficacy and credibility ratings, reflecting the assumption that individuals with higher academic self-efficacy would exhibit a more critical epistemic stance. Contrary to expectations, small but significant positive correlations emerged: academic self-efficacy was positively related to credibility of the scientist, $r = .09$, $p = .002$, and with credibility of the research findings, $r = .07$, $p = .024$. Thus, participants with higher self-efficacy were slightly more likely to perceive both the scientist and the research as credible.

5.3.5 Tentativeness and Credibility (H6)

Hypothesis 6 proposed that perceived tentativeness would be negatively correlated with credibility perceptions. However, the results did not support this hypothesis. The correlation between tentativeness and perceived credibility of the scientist was not significant, $r = -.02$, $p = .502$. Similarly, the correlation between tentativeness and perceived credibility of the research was also non-significant, $r = -.04$, $p = .223$. These small, non-significant correlations suggest that increased awareness of uncertainty in the research did not reduce perceived trustworthiness.

To examine whether the observed pattern held across the different experimental conditions, correlations between perceived tentativeness and both credibility measures were calculated separately for each group. Across all four conditions, these correlations were consistently small and non-significant (τs ranged from −.07 to +.05, all *p*s > .10), indicating that the absence of an association was not affected by framing or presentation style. Further statistical tests confirmed that these small differences in correlations were not meaningful. Comparisons across groups and between related measures within groups revealed no significant differences, and all confidence intervals for the differences included zero. This suggests that the numerical fluctuations, including occasional reversals in direction, likely reflect random variation rather than systematic effects. A complete correlation matrix of all measured variables is provided in Table 13, and detailed group-specific correlation results and statistical comparisons are presented in Table 14.

Table 13

Correlation Matrix of the Measured Scales

Variable	1	2	3	4
1. Perceived Tentativeness of the Findings	—			
2. Perceived Credibility of the Scientist	−.02	—		
3. Perceived Credibility of the Research Findings	−.04	.68**	—	
4. Academic Self-Efficacy	.03	.09	.07	—

Note. *N* = 1,105. p < .01. Correlations significant at this level are marked with **.

Table 14

Tentativeness & Credibility (Kendall's Tau-b, by Condition)

Condition	τ (Tentativeness, Scientist Credibility)	p	τ (Tentativeness, Findings Credibility)	p	n
Science-in-the-making × Cookbook-style	−.07	.101	−.07	.143	276
Ready-made science × Cookbook-style	−.04	.405	+.00	.982	275
Science-in-the-making × Scientific reasoning style	−.04	.391	−.03	.455	276
Ready-made science × Scientific reasoning style	+.05	.250	−.00	.917	278

Note. Kendall's tau coefficients. All correlations were non-significant ($p > .10$).

5.4 Discussion

These findings are particularly relevant for wildlife science communicators, who often face the challenge of conveying complex ecological processes and inherent scientific uncertainties to the public (KC et al., 2024; Mohan & Kelly, 2020). While our study did not directly investigate human-wildlife conflict scenarios, transparent communication of scientific uncertainty is known to be critical in these contexts, where stakeholder perceptions can influence management outcomes (KC et al., 2024; Morrison et al., 2008). Our findings on framing tentativeness as a feature of robust scientific reasoning may thus provide useful guidance for communicators working in such situations. In bat ecology, where conservation outcomes often hinge on public understanding and support, clearly articulating the reasoning behind scientific claims becomes especially important (Intemann, 2024; KC et al., 2024). This is particularly true in urban contexts, where anthropogenic pressures – such as light pollution and habitat fragmentation – disrupt bats' commuting corridors and roosting behaviors (Voigt & Kingston, 2016).

Against this backdrop, our study examined how different portrayals of scientific practices (*cookbook-style* vs. *scientific reasoning style*) and a scientists' thought processes (*science-in-the-making* vs. *ready-made science*), in the context of current field research on bat ecology and light pollution, as reported in a manuscript currently under review by Lewanzik et al. (2025), influence public perceptions of scientific credibility and tentativeness. Drawing on theories of science communication, epistemic cognition, and academic self-efficacy, we explored both the direct effects of video portrayals and the moderating role of individual traits in shaping public responses to urban wildlife science.

5.4.1 Summary of Findings

Contrary to our expectations, neither the portrayal of the scientist's thought process (H1) nor the depiction of scientific practices (H2) significantly affected perceived credibility. This suggests that the anticipated benefits of portraying science as *ready-made* or using explanatory reasoning formats may be more context-dependent than previously assumed. These results challenge widely held assumptions in science communication research that increased transparency, or epistemic elaboration automatically enhances perceived credibility (Fischer & Huff, 2025; Henkel et al., 2024; Intemann, 2024; Straka et al., 2021). They also speak to recent debates around epistemic trust and the limits of rationalist models of science understanding (Beets et al., 2025; Oreskes, 2019; Scheufele, 2014).

In contrast, Hypothesis 3 was clearly supported: Participants exposed to the *scientific reasoning style* condition perceived the research findings as significantly more tentative than those exposed to the *cookbook-style* condition. This effect was both statistically robust and substantial in magnitude ($\eta^2 = .38$), confirming that reasoning-based formats are highly effective at conveying the provisional nature of scientific knowledge. A smaller, yet statistically significant, main effect was also observed for the portrayal of the scientist's thought process ($\eta^2 = .01$). Given the minimal effect size, this result likely reflects the high statistical power afforded by the large sample. Nonetheless, it suggests that portraying science as a process in the making may modestly enhance perceptions of tentativeness, potentially by revealing the iterative and exploratory nature of scientific inquiry (Mayer et al., 2008). Importantly, this increase in perceived tentativeness did not appear to undermine credibility. While correlational patterns might suggest a potential link, this relationship was not directly tested and should therefore be interpreted with caution (Cobern et al., 2022; Flemming et al., 2020; Kimmerle et al., 2015; Thomas et al., 2025).

Hypothesis 6, which predicted a negative correlation between tentativeness and credibility, was not supported. Across all experimental conditions, no significant correlation was found – neither in the scientific reasoning nor in the *cookbook-style* presentations. This suggests that uncertainty, when framed as an integral feature of scientific reasoning, can be acknowledged without eroding public confidence. This aligns with growing scholarly consensus that communicating uncertainty transparently can foster epistemic humility and engagement, rather than confusion or distrust (Han et al., 2011; Schneider et al., 2022; Schneider, 2016). These findings offer valuable insights into wildlife and environmental science communication, especially in contested areas such as urban biodiversity, where public understanding of ecological complexity is crucial for conservation outcomes (Davies, 2021; Davies & Horst, 2016; Voigt & Kingston, 2016).

5.4.2 Role of Academic Self-Efficacy

Our findings add nuance to the presumed relationship between academic self-efficacy and critical science engagement. Hypothesis 4, which predicted a positive association between academic self-efficacy and perceived tentativeness, was not supported. Likewise, Hypothesis 5 was not confirmed: Contrary to expectations based on a more critical epistemic stance, academic self-efficacy showed a weak but positive correlation with credibility ratings for both the scientist and the research findings. This pattern suggests that individuals who feel more confident in their ability to understand science content may be more inclined to trust it, rather than scrutinize it more deeply. One possible explanation is that individuals with higher academic self-efficacy may identify more closely with the scientist's role or perspective, fostering greater trust in scientific information. Alternatively, it is conceivable that individuals with lower self-efficacy are, on average, overly and unjustifiably critical. These findings underscore the importance of further disentangling the constructs of epistemic humility, academic self-efficacy, and critical thinking dispositions in future research.

5.4.3 Practical Implications

Given the ecological importance and public sensitivity surrounding bat populations, especially in urban environments (Gutiérrez-Granados & Rodríguez-Zúñiga, 2024), our results suggest that portraying the reasoning behind bat research can foster trust without compromising scientific integrity. Our findings yield practical insights for science communication:

- Video-based formats in wildlife science regarding bat ecology seem to be effective tools in conveying the tentativeness of scientific knowledge, especially when using *scientific reasoning style* presentations of scientific practices.
- Tentativeness does not inherently undermine credibility. Communicators, particularly in fields such as wildlife or conservation science, can safely include elements of uncertainty as part of authentic science communication.
- Presenting science as a reasoning process, rather than a fixed set of facts, may foster epistemic awareness and reflective engagement with wildlife-related knowledge. By making the iterative and uncertain nature of ecological research visible, communicators can support more informed and participatory forms of public engagement, particularly in contexts where human–wildlife interactions are shaped by contested knowledge claims.
- Communication strategies should account for the diverse epistemic orientations audiences bring to science-related topics. While portrayals of *science-in-the-making* may not consistently enhance perceived credibility, they can still serve important educational and democratic functions. As noted in the human dimensions of conservation literature, fostering critical reflection and epistemic humility is key to building trust and legitimacy in wildlife governance (Straka et al., 2023). Integrating reasoning-based formats into science communication may thus support not only individual understanding but also societal capacity to navigate complex conservation challenges.

5.4.4 Methodological Strength and Clarification

Unlike many experimental studies using brief text snippets or simplified scenarios, this study employed fully developed video narratives of 13-18 minutes. Videos systematically varied in portraying scientific practices (*cookbook-style* vs. *scientific reasoning style*) and scientist’s thought processes (*science-in-the-making* vs. *ready-made science*) while maintaining equivalence in research content and structure. Each video depicted the full research process, including fieldwork, interpretation, and communication of uncertainty. This design enhances ecological validity and relevance for applied science communication (e.g., museums, media, education). The use of realistic video content suggests that the absence of credibility effects cannot be attributed to overly abstract stimuli; credibility perceptions appear robust even when scientific uncertainty is communicated through rich, narrative-driven media.

5.4.5 Limitations and Future Research

Despite its strengths, the study has several limitations that should be acknowledged. Although the sample was demographically diverse, it was limited to German-speaking participants, which may limit the transferability of findings to other linguistic and cultural contexts. Additionally, the study focused on academic self-efficacy as a moderating variable, whereas other relevant dispositional factors, such as interest in science, trust in scientific institutions, or need for cognition, were not included (Godžáková et al., 2025; Vaupotič et al., 2021; Wintterlin et al., 2022). These variables may interact with message features in meaningful ways and should be incorporated in future research to more fully capture the complexity of individual differences in responses to science communication on wildlife research.

Future studies could also explore whether portrayals of *science-in-the-making* have stronger effects in domains marked by higher levels of controversy or political sensitivity, such as climate change or vaccination, where public trust is more fragile and epistemic uncertainty more salient. Moreover, it remains an open question whether explanatory formats not only influence perceptions but also promote deeper conceptual understanding and behavioral engagement, thus helping bridge the gap between attitudes and actions.

Longitudinal and mixed-method research designs could offer further insight into how such communication strategies affect epistemic beliefs and trajectories of trust over time, potentially capturing delayed or cumulative effects. Qualitative approaches may further illuminate how individuals interpret and negotiate the presented information within their social and cultural contexts, thereby shedding light on the mechanisms underlying observed quantitative effects.

5.5 Conclusion

The present study offers empirical support for the effectiveness of extended, video-based portrayals of scientific practice, particularly when framed as reasoning processes, in communicating the tentativeness inherent to scientific knowledge. Crucially, these portrayals did not undermine perceived credibility, thereby addressing a long-standing concern in science communication regarding the potential trade-off between transparency and trust. While not all experimental manipulations produced the anticipated effects, the findings underscore the relevance of contextual factors, audience characteristics, and framing strategies in shaping public reception and interpretation of scientific information. These results highlight the importance of carefully designed communication strategies that balance transparency with maintaining trust, ultimately contributing to more informed public engagement with science.

6. General Discussion

6.1 Summary of Main Findings

This dissertation investigated how different representations of scientific research processes influence perceptions of tentativeness, credibility of research findings, and credibility of the scientist. Across four chapters, the findings consistently demonstrate that the way science is portrayed, particularly in terms of reasoning transparency and epistemic framing, has a measurable impact on how audiences interpret scientific knowledge.

Chapter 2 introduced a systematic video development framework that integrates scientific reasoning skills and nature of science categories. The framework distinguishes between macro, meso, and micro levels of video design, enabling controlled variation in how scientific practices and scientists' thought processes are presented. It provides a flexible structure for developing educational videos that make the epistemic complexity of science visible, thereby "opening the Black Box" of scientific inquiry.

Chapter 3 presented two online experiments with university students, comparing text-based and video-based representations of bat ecology research context from Thailand. The findings revealed that text-based formats without explanatory depth increased perceived tentativeness, while video-based formats emphasizing scientific reasoning enhanced perceived credibility of research findings. Importantly, a significant negative correlation was found between tentativeness and both credibility of the research findings and credibility of the scientist, suggesting a tension in how uncertainty is interpreted by academically trained audiences.

Chapter 4 extended the investigation to secondary school students in both classroom and lab-institute settings. While the manipulations did not yield significant effects in the classroom study, the lab-based intervention showed that authentic portrayals of scientists' thought processes (*science-in-the-making*) increased perceived tentativeness. Again, tentativeness was negatively correlated with both credibility measures, indicating that younger learners also struggle to reconcile uncertainty with trust in science.

Chapter 5 broadened the scope to the general public by applying the same framework to a new research context: bat responses to light pollution in Germany. In a large-scale online experiment with over 1,000 participants, elaborated representations of scientific reasoning and thought processes significantly increased perceived tentativeness.

However, unlike in previous studies, tentativeness was not negatively correlated with credibility of the research findings or credibility of the scientist. This suggests that, in broader audiences, uncertainty can be communicated without undermining trust, provided it is framed transparently and contextually.

Taken together, these findings demonstrate that the portrayal of scientific reasoning and uncertainty plays a crucial role in shaping public and educational perceptions of science. A particular strength of this dissertation lies in the methodological consistency across all empirical studies. While media formats, audience groups, research contexts, and scientist portrayals were systematically varied, the same core variables and overarching research question were maintained throughout. This design enabled a controlled investigation of how portrayals of scientific reasoning affect perceptions of tentativeness and credibility across diverse conditions. The consistent effects observed across studies underscore the robustness of the framework and its applicability in both educational and public science communication.

The results support the central thesis of this dissertation: epistemic transparency is essential for fostering scientific literacy and trust in science.

Notably, in Chapter 5, the absence of a negative correlation between tentativeness and credibility may have been influenced by the change in protagonist, from male to female. While the materials and measured variables were comparable, ceiling effects in both credibility scales limited the interpretability of any potential gender-related differences. Nevertheless, recent research suggests that female scientists may be perceived as more trustworthy and competent in public-facing science communication (Hubner & Bullock, 2025). These findings highlight the need for future studies to systematically investigate how scientist characteristics, including gender, narrative framing, and perceived expertise, interact with audience perceptions of tentativeness and credibility.

6.2 Strengths and Limitations

First, a major strength of this dissertation lies in its conceptual framework, which systematically integrates scientific reasoning, nature of science, and multimedia learning principles. Its three-tiered structure, macro, meso, and micro levels, provides both theoretical depth and practical flexibility, allowing the design to be adapted to new research contexts and educational settings. The framework offers a coherent and operationalizable approach to visualizing scientific reasoning and epistemic complexity in video-based science communication. It supports the development of video materials that authentically depict scientific practices while systematically varying key epistemic features. To date, no comparable framework offers such a comprehensive approach for both educational and public contexts.

Second, the empirical design encompasses multiple audiences, media formats, and research contexts, enhancing the generalizability and robustness of the findings. By including university students, secondary school students, and members of the general public, the dissertation shows that the effects of epistemic framing are not limited to a single demographic. Likewise, the use of both text-based and video-based materials provides a more nuanced understanding of how modality interacts with scientific reasoning style and credibility perceptions. However, these variations were not systematically manipulated or directly compared, which limits the ability to draw causal conclusions about the effects of audience, format, or context. Moreover, despite the multi-dimensional design, the generalizability of the findings remains somewhat constrained, as the studies were conducted within a limited number of educational and cultural contexts. Future research should test the framework across additional settings to further validate its robustness and ecological validity.

Third, the video stimuli themselves represent a methodological innovation. They combine scripted sequences, authentic interview segments, and voice-over narration, aligning with best practices in science communication that emphasize narrative coherence, emotional engagement, and epistemic transparency (Brame, 2016; Erduran et al., 2021; Evagorou et al., 2015). This hybrid format allows the portrayal of both the procedural and reflective dimensions of scientific inquiry, making the videos suitable for diverse educational settings.

Overall, these strengths position the dissertation as a significant contribution to research on science communication and education. Despite these strengths, the studies also reveal areas for further development. First, while the framework allows for systematic variation, the micro-level manipulations, particularly the distinction between “science-in-the-making” and “ready-made science”, were central to the study design. In some cases, these differences may have been too subtle to elicit strong effects, especially among younger or less scientifically literate audiences. One limitation is that each participant was exposed to only one version of the video stimulus, randomly assigned. This design does not allow direct comparisons within individuals across different portrayals of scientific reasoning. Future studies could present multiple video variations to the same participants to evaluate differences in perceived credibility and tentativeness. While within-subject designs may offer deeper insights into how subtle framing effects, between-groups designs better reflect how audiences typically encounter science communication in real-world contexts.

Another limitation concerns the tentativeness scale, which showed only moderate internal consistency in some samples. Perceptions of tentativeness represent a relatively new construct in video-based science communication, and established, highly reliable measures were not available. The scale was used despite its psychometric limitations because it captures a theoretically important aspect of science communication.

Consequently, the results should thus be interpreted accordingly and regarded as initial empirical insights, informing both the refinement of measurement tools and the conceptualization of tentativeness in future research.

Additionally, the reliance on self-report measures may have constrained the depth of insight into participants' epistemic engagement. While well-established, these instruments do not capture behavioral or longitudinal effects. Future research could complement survey data with qualitative interviews, eye-tracking, or delayed follow-ups to assess how perceptions evolve over time and influence trust, learning, or decision-making. Alternatively, belief updating could serve as a more direct indicator of epistemic change, as evaluations alone may not reliably reflect whether individuals revise their views in response to scientific information.

Finally, an additional methodological consideration relates to the change in protagonist in Chapter 5, from male to female, which may have influenced audience perceptions. Although the materials were matched and both credibility scales showed ceiling effects, this shift highlights the need for future studies to systematically investigate how scientist identity and representation affect trust and epistemic judgments. Factors such as gender, narrative voice, and perceived expertise may all shape how tentativeness is interpreted, particularly in broader public samples.

In summary, these limitations do not undermine the validity of the findings but rather highlight the complexity of the topic and the need for continued methodological and theoretical development. They point to promising directions for future research and underscore the relevance of this dissertation as a foundation for advancing science communication and education in epistemically rich ways.

6.3 Theoretical Implications

The findings of this dissertation yield several theoretical implications for research in science education, epistemic cognition, and science communication.

First, the results support the conceptual distinction between *ready-made science* and *science-in-the-making* as proposed by Latour and Woolgar (1986, 2013). Across all studies, portrayals that made the reasoning process visible, especially those that highlighted uncertainty, deliberative thinking, and methodological decision-making through video-based formats, were more likely to increase perceptions of tentativeness. This suggests that audiences are sensitive to how scientific processes are represented: finalized portrayals tend to convey certainty, while provisional portrayals invite reflection on the evolving nature of knowledge.

Importantly, the tentative nature of scientific knowledge does not imply arbitrariness or unreliability. Rather, it reflects the self-correcting and cumulative character of science, in which individual findings gain meaning and robustness through replication, theoretical integration, and ongoing scrutiny (van der Bles et al., 2019).

The enduring relevance of the “Black Box” metaphor is thus reaffirmed, offering a powerful analytical lens for examining how epistemic complexity is either concealed or revealed in science communication.

Second, the dissertation extends and empirically validates the framework of *Styles of Scientific Reasoning* by Kind and Osborne (2017). The video development framework operationalized these reasoning styles in a way that allowed for systematic variation across media formats and audiences. The findings demonstrate that explanatory depth, especially when procedural and epistemic knowledge are made explicit, can enhance credibility and foster epistemic awareness. Building on this, the results align closely with the theoretical foundations laid out in Chapter 2, where the integration of epistemic cognition, multimedia learning, and nature of science frameworks provided the conceptual backbone for the study design and interpretation. The observed effects of reasoning transparency and explanatory depth confirm that audiences benefit from formats that make epistemic features visible – a core concern of epistemic cognition research (Davies, 2021; Hofer & Pintrich, 1997; Iordanou, 2016). Moreover, the successful application of multimedia principles, such as Mayer’s modality and coherence principles, supports the assumption that video-based formats can effectively convey complex epistemic content when designed with cognitive load in mind (Brame, 2016;

Mayer, 2009, 2024). Finally, the consistent relevance of nature of science categories – especially tentativeness, subjectivity, and empirical basis – across all studies underscores the importance of embedding these dimensions not only in educational curricula but also in public-facing science communication.

Third, the findings contribute to ongoing debates about the nature of science and its role in science education. While traditional nature of science frameworks often emphasize declarative knowledge about scientific principles, this dissertation highlights the value of integrating (epistemic) scientific practices and scientists' thought processes into instructional design. The proposed framework combines deductive nature of science categories (e.g., tentativeness, subjectivity, creativity) with inductive, case-based insights from authentic research processes, thereby responding to calls for a more holistic and situated understanding of nature of science (Allchin, 2011; Dagher & Erduran, 2016).

At the same time, the results reveal limitations in how these theoretical models are received by different audiences. While university students and secondary school students showed consistent negative correlations between tentativeness and credibility, the general public did not. This indicates that epistemic framing interacts with prior knowledge, trust dispositions, and cognitive expectations, and that theoretical models must be sensitive to these audience-specific factors.

Viewed holistically, the integration of nature of science, scientific reasoning, and multimedia learning offers a promising interdisciplinary foundation for future research. Yet further work is required to refine these models in light of audience interpretation, media effects, and trust formation, and to investigate how epistemic cognition develops across educational levels and cultural contexts.

6.4 Practical Implications

This dissertation offers several practical insights that are relevant for science communication, formal education, and public engagement with science. As outlined in the General Introduction, international assessments such as PISA consistently reveal that students struggle to grasp how scientific knowledge is generated, revised, and validated. Moreover, public trust in science is often challenged when findings appear uncertain or contradictory. These observations underscore the need for formats that make the epistemic nature of science visible and accessible.

In science communication, the findings show that it is possible to communicate epistemic features such as uncertainty and tentativeness without undermining credibility. This challenges the widespread assumption that transparency about the provisional nature of scientific knowledge necessarily reduces trust. Instead, when scientific reasoning is made visible and contextualized appropriately, audiences, especially from the general public, can engage with uncertainty in a constructive way. This opens up new possibilities for communicating complex topics such as climate science, wildlife research, or public health in a more epistemically honest and dialogical manner. For instance, communicators might explicitly highlight competing hypotheses or explain why scientific conclusions evolve over time, thereby fostering trust through openness rather than oversimplification.

In school education, the video development framework provides a flexible tool for integrating authentic scientific practices into teaching. It enables educators to select and structure content based on scientific reasoning skills and categories related to nature of science, while adapting the presentation style to different age groups and learning environments. Empirical findings indicate that students benefit from gaining insight into how scientists think and make decisions, rather than merely learning about final results. This aligns with current curricular goals that emphasize inquiry-based learning, critical thinking, and the development of scientific literacy. At the same time, educational videos respond to the increasing demand for more digital and decentralized teaching formats in schools, thereby supporting broader educational innovation and accessibility. Given the PISA findings, such formats may help address persistent gaps in students' epistemic understanding and foster more reflective engagement with scientific content.

For the general public, the results highlight the importance of making the process of knowledge generation visible. In times of misinformation and declining trust in science, portraying science as a dynamic and reflective activity can help bridge the gap between experts and lay audiences. The study involving over 1,000 participants demonstrated that even complex epistemic features, such as the tentativeness of research claims, can be communicated effectively, provided that the format is accessible and the framing is attuned to audience expectations. This has implications for museums, media platforms, and citizen science initiatives aiming to foster public understanding of science. By showing not only what scientists know but *how* they come to know it, communicators can promote a more resilient and informed public discourse.

Follow-up research should explore how these findings can be translated into scalable interventions, such as modular video series, teacher training programs, or public outreach formats. The field of science communication is evolving rapidly, and the need for epistemically rich formats is more urgent than ever. By combining theoretical clarity with practical adaptability, the framework developed in this dissertation offers a foundation for future innovations in science education and communication.

6.5 Future Research Directions

Building on the findings of this dissertation, several promising directions for future research emerge, both in terms of methodological refinement and theoretical advancement.

First, future studies should explore within-subject designs that allow participants to compare multiple versions of research process presentations. In the present work, each participant was exposed to only one video condition, which limits insight into how individuals perceive and differentiate between framing styles. Presenting all variations, for example, the *cookbook-style* versus the *scientific reasoning style*, and *ready-made science* versus *science-in-the-making*, to the same individuals could reveal more nuanced evaluations and foster metacognitive reflection on scientific communication. This approach aligns with calls for deeper engagement with epistemic cognition (Elby et al., 2016; Iordanou, 2016).

Second, the development of more robust and context-sensitive instruments for measuring perceived tentativeness is essential. While the current scale provided valuable insights, its moderate internal consistency in some samples suggests that tentativeness is a complex and multifaceted construct. Future work could draw on recent advances in epistemic belief research to develop refined tools that better capture how individuals interpret uncertainty in scientific contexts.

Third, future research should investigate how audience characteristics, such as prior knowledge, trust in science, academic self-efficacy, and media literacy, interact with framing effects. The finding that tentativeness did not negatively correlate with credibility in the general public sample (Chapter 5) suggests that contextual and dispositional factors play a critical role in how uncertainty is received. Comparative studies across cultures, educational systems, or media environments could help clarify these dynamics (Beets et al., 2025; Gustafson & Rice, 2020).

Fourth, longitudinal designs could assess how exposure to epistemically rich science communication influences scientific literacy over time. While the present studies focused on immediate perceptions, future work could examine whether repeated engagement with reasoning-based formats leads to more stable changes in trust, understanding, and critical evaluation of scientific claims. This would respond to recent calls for durable science education interventions (Feinstein & and Waddington, 2020; Lombardi et al., 2016).

Finally, the framework developed in this dissertation could be extended to new domains of science, such as climate modeling, biomedical research, or AI ethics, fields where uncertainty is both inherent and socially contested. Applying the video development framework to these areas would test its adaptability and relevance beyond ecology and education and contribute to the broader goal of fostering epistemic resilience in public discourse (Höttecke & Allchin, 2020; Intemann, 2024).

Viewed in its entirety, these directions underscore the potential of this dissertation not only as a contribution to current debates, but as a starting point for a broader research agenda that connects science education, communication, and epistemic psychology.

7. Conclusion

This dissertation explored how the presentation of scientific research processes – particularly through video-based formats – shapes public and educational perceptions of tentativeness, credibility of research findings, and credibility of the scientist. At its core lies the question of how science can be communicated in ways that are both epistemically transparent and trustworthy.

Across three empirical study packages, the findings demonstrate that audiences respond sensitively to how scientific reasoning is portrayed. When uncertainty and deliberation are made visible through authentic representations of scientists' thought processes and explanatory depth in the depiction of scientific practices, tentativeness becomes more salient. Importantly, this does not necessarily diminish credibility. Especially in broader public contexts, uncertainty can be communicated without eroding trust, provided it is framed with clarity and contextual relevance.

The video development framework introduced in this dissertation provides a novel and transferable approach for designing educational and communicative materials that reflect the complexity of scientific inquiry. By integrating scientific reasoning skills, nature of science categories, and multimedia learning principles, it enables the creation of materials that go beyond the transmission of results and instead illuminate the process of knowledge generation.

In times of increasing skepticism toward science and rising demands for transparency, this work contributes to a deeper understanding of how epistemic features can be communicated effectively. It shows that tentativeness is not a weakness to be concealed, but a strength to be explained. Scientific literacy, trust, and critical thinking can be fostered not by simplifying science, but by opening its "Black Box" and inviting audiences to engage with its reasoning.

This dissertation closes with the conviction that science communication and education must embrace the provisional nature of knowledge – not as a deficit, but as a defining feature of scientific progress. The framework and findings presented here offer a foundation for future research, practice, and dialogue, aiming toward a more reflective, transparent, and epistemically engaged public understanding of science.

Ultimately, this dissertation contributes to a growing body of research that seeks to reframe science communication as an epistemically rich, dialogical process. By demonstrating that uncertainty can be communicated without eroding trust, and that audiences are capable of engaging with the complexity of scientific reasoning, it challenges prevailing assumptions and opens new avenues for research and practice. The video development framework presented here offers a scalable and adaptable model for fostering scientific literacy across educational and public contexts. In doing so, it lays the groundwork for a more transparent, reflective, and resilient engagement with science in an increasingly complex world.

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