

# MARTIN-LUTHER-UNIVERSITÄT HALLE-WITTENBERG

# Supporting Science Pre-service Elementary Teachers in Learning to Plan Modelingbased Investigations

Publication-based Thesis

to attain the title of Doctor of Philosophy (Dr. phil.)

submitted

to the Faculty of Philosophy III

**Educational Sciences** 

of Martin Luther University Halle-Wittenberg,

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Defense Date: September 12th 2022

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# List of Abbreviations

DBR	Design-based Research	
e.g.	exempli gratia (Latin for the English for the sake of example)	
i.e.	id est (Latin for the English that is to say or in other words)	
ILIAS ®	Integriertes Lern-, Informations- und Arbeitskooperations-System [German for "Integrated Learning, Information and Work Cooperation System"])	
КМК	Kultusministerkonferenz (Germany)	
MBIs	Modeling based investigations	
MBLS-A	Ministerium für Bildung des Landes Sachsen-Anhalt (Germany)	
MRs	Material representations	
NGSS	Next Generation Science Standards (United States of America)	
NRC	National Research Council (United States of America)	
OECD	Organisation for Economic Co-operation and Development	
РСК	Pedagogical Content Knowledge	
PISA	Programme for International Student Assessment	
PV	Professional Vision	
p.	Page	
p.p.	Pages	
TBs	Transformation Boxes	

# Abkürzungsverzeichnis

MBUs	modellbasierte Untersuchungen
z.B.	zum Beispiel
d.h.	das heißt
S.	Seite

#### Acknowledgments

I would like to express my deepest gratitude to my supervisors Prof. Dr. Andres Acher and Prof. Dr. Scott McDonald, for their guidance during this research. Their comprehensive insights and knowledge in the science teacher education field steered me through this research and have made this an inspiring experience for me. Special thanks to Prof. Dr. Michael Gebauer for his support throughout the process.

I would like to express my sincere gratitude to all participants from Martin-Luther-Universität Halle-Wittenberg (MLU) that took part in the studies, who impacted and inspired me. I would like to thank the research team at Pennsylvania State University (PSU) for their collaborative effort during my visit. I would also like to acknowledge the thoughtful and detailed feedback of the Bielefeld Universität, PSU, and MLU research group members.

Many thanks to COLFUTURO (Fundación para el Futuro de Colombia) and the DAAD (Deutscher Akademischer Austauschdienst). Their economic support during the first two years of my research via the country-related cooperation program was central to making this research possible.

I am extremely grateful to my colleagues and friends, especially Julio Tovar, Ivonne Rodríguez, Jonathan McCausland, Kathryn Bateman, Julia Elsner, and Sergej Urdacev, for our friendly chats and your personal support in my academic endeavors.

I could not have undertaken this journey without my husband, Sergio I. Acosta. His patience, encouragement, and belief in me have kept my spirits and motivation high during this process.

Thank you to my family. In special to my parents, Edilma and Florentino, and my brother, Daniel, for their endless support. They have always stood behind me, and this was no exception.

#### **Erweitere Zusammenfassung**

Bei der aktuellen Dissertationsarbeit handelt es sich um eine "Design-Based Research" (DBR)-Forschungsarbeit mit zwei iterativen Zyklen. Sie zielt darauf ab, didaktische Unterstützungen und die damit verbundenen pädagogischen Werkzeuge zu entwerfen, zu implementieren und zu analysieren. Dies soll angehende Sachunterrichtsstudierende beim Lernen unterstützen, um modellbasierte Untersuchungen (MBUs) zu planen. Diese Art der Planung MBUs betont die Einbindung der Schüler\*innen in Modellierung als wissenschaftliche und epistemische Praktik. Modellierung besteht aus der gemeinsamen Konstruktion von Verständnissen, die disziplinäre Kernideen mit der Modellierungspraktik integrieren, um zu verstehen, wie und warum etwas in der Welt passiert (Passmore et al., 2017).

Wenn Schüler\*innen in die wissenschaftliche Modellierung eingebunden werden, können sie die Naturphänomene durch die Entwicklung von Modellen verstehen und gleichzeitig ihr Verständnis der Praktik und der disziplinären Kernideen konstruieren (Acher, 2014; Manz, 2012; Shim & Kim, 2018). Diese Einbindung ermöglicht es den Schüler\*innen auch, die Natur und den Zweck von Modellen zu verstehen und sie in eine sinnbildende Praktik einzubeziehen. in der sie verstehen, was sie tun und warum sie es tun (Metamodellierungswissen, Schwarz et al., 2009). Modelle sind somit sinnbildende Werkzeuge, die zwischen natürlichen Phänomenen (was wahrgenommen wird) und den disziplinären Kernideen vermitteln, die zur Erklärung oder Voraussagung der laufenden Prozesse in diesen Phänomenen verwendet werden können (Acher, Arcà, & Sanmartí, 2007; Louca & Zacharia, 2019).

In der Schule können Lehrer\*innen Schüler\*innen ermutigen und unterstützen, Modelle zu entwickeln und sie als sinnbildende Werkzeuge zur Erklärung von Phänomenen durch MBUs zu verwenden (Campbell et al., 2019). MBUs betonen Lehrpraktiken wie Planung, Durchführung und Nachbesprechung auf der Grundlage, dass die Einbindung von Schüler\*innen in die wissenschaftliche Modellierung ein iterativer Prozess ist (Schwarz et al., 2009). Es bedeutet auch, dass sich Modelle ändern und entwickeln, je nachdem, was die Schüler\*innen aus ihren Untersuchungen über das Phänomen, disziplinäre Kernideen und die Modellierungspraxis lernen (Lehrer & Schäuble, 2012).

Die Planung komplexer Praktiken wie dieser MBUs ist für berufstätige Lehrer\*innen (Miller & Kastens, 2018) und noch mehr für angehende Lehramtsstudierende immer noch schwierig (Karlström & Hamza, 2021; Windschitl et al., 2012). Planung ist eine zentrale Lehrpraktik, die ein wesentlicher Bestandteil der professionellen Arbeit von Lehrer\*innen ist. Die Unterrichtsplanung zielt dabei darauf ab, den Unterricht so zu strukturieren, dass Schüler\*innen disziplinäre Kernideen lernen können, wenn sie an wissenschaftlichen Praktiken wie der Modellierung partizipieren (Windschitl et al., 2018).

Diese Planung von MBUs bringt zwei Hauptherausforderungen insbesondere für angehende Sachunterrichtsstudierende mit, die in ihrem beruflichen Lernprozess typischerweise ein Verständnis für disziplinäre Kernideen und wissenschaftliche Modellierung entwickeln sollen. Erstens fühlen sich angehende Sachunterrichtsstudierende oft unsicher in Bezug auf ihr Wissen über naturwissenschaftliche Inhalte (Gunckel, 2013; Zembal-Saul, 2018). Auch fehlt ihnen oft die Erfahrung, wie dieses Wissen durch wissenschaftliche Praktiken wie Modellierung generiert wird (Windschitl & Thompson, 2006). Sie nutzen zunehmend wissenschaftliche Inhaltsressourcen wie Online-Videos, um ihnen zu helfen, disziplinäre Kernideen zu verstehen (Baltaci-Goktalay & Ozdilek, 2010; Beach, 2020). Diese Videos ermöglichen es ihnen jedoch nicht direkt, epistemisch zu erfahren, wie diese Ideen in die Praktik der wissenschaftlichen Modellierung integriert werden können. Daher sehen sie wahrscheinlich weiterhin wissenschaftliche Kernideen und Praktiken als konkurrierende Lernziele, die während der Naturwissenschaftsunterricht erreicht werden müssen (Berland et al., 2015).

Zweitens haben angehende Sachunterrichtsstudierende als Anfänger\*innen in der Regel keine Erfahrung mit der Planung, wie Schüler\*innen sich mit forschungsbasierter Wissenschaft beschäftigen können (Kademian & Davis, 2018). Um beispielsweise zu lernen, wie man MBUs plant, ist es für angehende Sachunterrichtsstudierende relevant, dass sie drei entscheidende Komponenten lernen: (a) natürliche Phänomene klar definieren, (b) modellbasierte Fragen formulieren, die Schüler\*innen untersuchen können, und (c) eine kohärente Abfolge von Aktivitäten als Phasen von MBUs festlegen (Benedict-Chambers et al., 2017; Louca & Zacharia, 2012). Durch diese Komponenten drei ist möglich, die es Untersuchungsbedingungen zu gestalten, an denen Schüler\*innen beteiligt sind. Dies soll bezwecken, dass Schüler\*innen ""getting a grip" on the material world to participate in the development of means to answer their inquiries" [die materielle Welt in den Griff zu bekommen, um an der Entwicklung von Mitteln zur Beantwortung ihrer Fragen mitzuwirken]" (Lehrer & Schäuble, 2012, S. 717).

Die Forschung in der naturwissenschaftlichen Lehrer\*innenbildung hat das Design praxisorientierter Lernumgebungen als effektive Möglichkeit betont. angehende Lehramtsstudierende beim Erlernen komplexer Lehrpraktiken wie der Planung von MBUs zu unterstützen (Forzani, 2014; McDonald et al., 2013). Verschiedene empirische Studien haben die Bedeutung von Designs hervorgehoben, die angehende Lehramtsstudierende bei der Entwicklung von Kenntnissen über wissenschaftliche Ideen, Modelle und Modellierung unterstützen, um sie auf ihre zukünftige Lehrpraktiken vorzubereiten (Carpenter et al., 2019; Danusso et al., 2010; Yenilmez Turkoglu & Öztekin, 2016). Andere empirische Studien, die das professionelle Lernen angehender Lehramtsstudierende für modellbasierten Unterrichts untersucht haben, haben Designs hervorgehoben, die sie bei der Entwicklung von Modellen

unterstützen (Kenyon et al., 2011; Windschitl et al., 2008). Aus der Entwicklung dieser Modelle können die angehender Lehramtsstudierende pädagogisch entscheiden, wie sie wissenschaftliche Modellierung in ihre Unterrichtspläne integrieren können. In keinem dieser Fälle werden jedoch Lernumgebungen entworfen oder das Lernen untersucht, das damit verbunden ist, wie angehende Lehramtsstudierenden epistemische und pädagogische Bedeutungen durch Diskurse aushandeln, um ihr professionelles Verständnis aufzubauen.

Um einen Beitrag zur Schließung dieser Lücke zu leisten, dreht sich das zentrale Argument der Dissertationsarbeit um das Design von Lernumgebungen mit didaktischen Unterstützungen und den dazugehörigen pädagogischen Werkzeugen. Diese beinhalten ein biologiespezifisches epistemisches Werkzeug und haben daher das Potenzial, die Aushandlung von epistemischen und pädagogischen Bedeutungen der angehenden Sachunterrichtsstudierende im Moment durch den Diskurs zum Lernen (Entwicklung eines "Professional Vision, PV) für die Planung von MBUs zu unterstützen.

Die Aushandlung epistemischer Bedeutungen der angehenden Sachunterrichtsstudierende ist notwendig, um sie darauf vorzubereiten, wie Schüler\*innen in den Prozess der wissenschaftlichen Modellierung eingebunden werden können. Durch die wissenschaftliche Modellierung sollen Schüler\*innen ein Verständnis für disziplinspezifische Kernideen entwickeln und erfahren, wie diese Ideen in den sich entwickelnden Modellen generiert werden (Acher et al., 2007; Manz, 2012; Ryu et al., 2015). Die Aushandlung pädagogischer Bedeutungen der angehenden Sachunterrichtsstudierende ergibt sich aus ihrer authentischen oder "echten" Partizipation an der Lehrpraktik der Planung von MBUs durch Diskurse (über die Definition von Naturphänomenen, die Formulierung modellbasierter Fragen und die Einrichtung einer kohärenten Abfolge von Aktivitäten). Dies ist für die naturwissenschaftliche Lehrer\*innenbildung von entscheidender Bedeutung, da – aus einer soziokulturellen Lernperspektive– Diskurse dann entstehen, wenn angehende Lehramtsstudierende mit den sozialen und physischen Ressourcen interagieren.

In diesem Sinne befasst sich diese Dissertationsarbeit mit dem Lernen von angehenden Sachunterrichtsstudierenden als Entwicklung einer "Professional Vision" (PV), insbesondere der PV Grundlage (Goodwin, von 1994). Lernen bedeutet, dass angehende Sachunterrichtsstudierende ein PV für die Planung von MBUs entwickeln, anstatt vorgegebene Kenntnisse oder Fähigkeiten in Bezug auf Wissenschaft, wissenschaftliche Modellierung oder Planung von MBUs zu erwerben. Angehende Lehramtsstudierende lernen, indem sie eine PV aushandeln, die darin besteht, epistemische Bedeutungen auszuhandeln, um zu verstehen, dass disziplinäre Kernideen Biologie) spezifische (z.B. und die wissenschaftliche Modellierungspraktik miteinander integriert sind, anstatt konkurrierende Ziele darzustellen. Darüber hinaus besteht diese PV darin, pädagogische Bedeutungen auszuhandeln, um den Unterricht in Form von MBUs zu strukturieren und zu sequenzieren sowie das Lernen der Schüler\*innen während einer Untersuchung natürlicher Phänomene zu leiten und zu unterstützen.

Ausgerichtet auf den DBR-Ansatz und angesichts des Schwerpunkts auf den Diskursen von angehenden Sachunterrichtsstudierenden nutzt die Dissertationsarbeit qualitative Methoden, um zu entwerfen und zu untersuchen, wie sie lernen, MBUs zu planen. DBR betont das theoriebasierte Design von Lernumgebungen als Forschungskontexte und eine ständige Analyse von Prozessen innerhalb dieser Kontexte, um das Design und Implementierung zu verbessern. Die Dissertationsarbeit entsteht im Rahmen eines Seminars für angehende Sachunterrichtsstudierende an einer deutschen Universität. Dieser Kontext ist geeignet, weil er sich praxisorientierten Standpunkt ausrichtet, angehende an einem der Sachunterrichtsstudierenden ermutigt, aus einer soziokulturellen Perspektive zu lernen. Sie haben die Möglichkeit, in großen und kleinen Gruppendiskussionen (z.B. Vorlesungen und

Seminaren) verschiedene wissenschaftliche Kernideen der Naturwissenschaften Disziplinen (z. B. Chemie, Biologie, Physik und Geowissenschaften) zu erlernen. Gleichzeitig lernen sie, wie sie diese Ideen integriert in die wissenschaftliche Modellierung durch die Planung von MBUs angehen können.

Das Design der Dissertationsarbeit in den zwei iterativen DBR-Zyklen betont drei Hauptelemente: (a) Artikulation von drei authentischen und situierten didaktische Unterstützungen, um angehende Sachunterrichtsstudierende dabei zu unterstützen, pädagogische Bedeutungen auszuhandeln, während sie an den drei kritischen Komponenten der Planungspraxis partizipieren (d.h. natürliche Phänomene klar definieren, modellbasierte Fragen formulieren, die Schüler\*innen untersuchen können, und eine kohärente Abfolge von Aktivitäten als Phasen von MBUs festlegen), (b) Verwendung von pädagogischen Werkzeugen mit Aufforderungen in Form von offenen Fragen und visuellen Darstellungen zur Unterstützung der entstehende Prozesse von angehenden Sachunterrichtsstudierenden während der Zusammenarbeit in einer Gruppe und (c) Verkörperung eines disziplinspezifischen (z. B. Biologie) epistemischen Werkzeugs innerhalb dieser pädagogischen Werkzeuge, um angehende Sachunterrichtsstudierende dabei zu unterstützen, epistemische Bedeutungen auszuhandeln, während sie an der Modellierungspraktik partizipieren.

"Professional Vision" (PV, Goodwin, 1994) wird als theoretischer und analytischer Rahmen verwendet, um das Lernen von angehenden Sachunterrichtsstudierenden während der beiden iterativen Zyklen zu interpretieren. Die drei diskursiven Praktiken dieses Rahmens, nämlich "Highlighting", "Coding" und "Material Representations" (MRs), dienen als Linse zur Analyse der Diskurse von angehenden Sachunterrichtsstudierenden. Diese Diskurse sind Gesprächs- und Handlungsweisen, um Bedeutungen auszuhandeln, während sie sozial an den didaktischen Unterstützungen partizipieren und mit den pädagogischen Werkzeugen interagieren in der praxisbasierten Lernumgebung. "Highlighting" bedeutet, Merkmale einer Domäne hervorzuheben, indem sie irgendwie markiert werden (z. B. darauf hinweisen, farbige Markierungen verwenden, ihre Relevanz ausdrücken). "Coding" besteht darin, Bedeutung zu verleihen oder die relevanten Merkmale in organisierte Schemata umzuwandeln, die sich auf die kulturellen Praktiken des Berufsstands beziehen. "Material Representations" sind Artefakte, die die Organisation und überzeugende Darstellung relevanter Merkmale dieser professionellen Praktiken unterstützen.

Das erste empirische Manuskript (Manuskript I) erweitert die Erkenntnisse des ersten iterativen Zyklus (Téllez-Acosta et al., 2022a). Manuskript I konzentriert sich auf die Untersuchung, wie angehende Sachunterrichtsstudierende Bedeutungen rund um disziplinäre Kernideen, Modellierung und Planung von MBUs für ihre zukünftigen Schüler\*innen aushandeln, während sie mit der bereitgestellten Unterstützung (d.h. didaktische Unterstützungen und pädagogische Werkzeuge) arbeiten. Der zentrale Beitrag zur naturwissenschaftlichen Lehrer\*innenbildung, der sich aus dieser ersten Studie ergab, bestand darin, dass das biologiespezifische epistemische Werkzeug (Transformationsboxen, TBs), das in die didaktischen Unterstützungen und die damit verbundenen pädagogischen Werkzeuge eingebettet ist, die Flexibilität der angehenden Sachunterrichtsstudierende im Umgang mit disziplinären Kernideen und wissenschaftlichen Modellierung fördert (d.h. epistemische Aushandlung). Dieses TB-Tool eröffnet auch Möglichkeiten zur Strukturierung der modellbasierten Untersuchung (d.h. pädagogische Aushandlung).

Auf der Grundlage dieses ersten Zyklus wurden die didaktischen Unterstützungen und die zugehörigen pädagogischen Werkzeuge für den zweiten iterativen Zyklus neugestaltet. Diese Neugestaltung wurde unter Berücksichtigung von zwei Hauptkriterien durchgeführt: (a) Neustrukturierung der didaktischen Unterstützungen, um die Aspekte der Planung von MBUs hervorzuheben, und (b) Vereinfachung der pädagogischen Werkzeuge für produktivere Diskurse (d.h. Diskussionen, die helfen, spezifischere Aspekte der Praxis zu verstehen). Der zweite Iterationszyklus untersucht, wie angehende Sachunterrichtsstudierende bei der Aushandlung von Bedeutungen rund um die Planung von MBUs das zweigeteilte Ziel dieser Praxis verstehen: epistemisch und pädagogisch. Die Hauptergebnisse dieses zweiten Zyklus entsprechen einem anderen empirischen Manuskript, das als Buchkapitel veröffentlicht wurde (Manuskript II) und als theoretisches Manuskript (Manuskript III).

Manuskript II konzentriert sich auf die Untersuchung, wie angehende Sachunterrichtsstudierende lernen, MBUs in einer praxisbasierten Blended-Learning-Umgebung zu planen, in der die (neu) gestalteten didaktischen Unterstützungen und zugehörigen Tools als "Multimedia-Tools" im Managementsystem ILIAS® implementiert wurden (Tellez-Acosta et al., 2021). Die "Multimedia-Tools" wurden unter Verwendung verschiedener verfügbarer webbasierter Ressourcen (z. B. Foren, Blogs und Etherpads) organisiert, die das Potenzial haben, das professionelle Lernen von angehenden Sachunterrichtsstudierenden durch schriftliche Diskurse zu unterstützen. Der Hauptbeitrag dieser Studie zur naturwissenschaftlichen Lehrer\*innenbildung besteht darin, dass eine zielgerichtete Kombination von webbasierten Ressourcen die Diskussion und die Partizipation der angehenden Sachunterrichtsstudierende bei jeder der vorgeschlagenen Aufgaben verbessert.

Diese Studie (Manuskript II) legt nahe, dass angehende Sachunterrichtsstudierende durch die epistemische (d.h. ein biologiespezifisches epistemisches Werkzeug) und disziplinäre Komponenten (d.h. Videos mit Online-Inhalten) unterstützt werden, indem sie Aspekte der Kernideen der Biologie in Erklärungsmodelle integrierten und gleichzeitig an der wissenschaftlichen Modellierung partizipieren. Darüber hinaus zeigt die Studie auf, dass die praktischen (d.h. Fokus auf bestimmte Aspekte der Planung von MBUs) und interaktiven (d.h. webbasierte Ressourcen wie Foren, Blogs, Datenerfassungstabellen und Etherpads) Komponenten das Engagement innerhalb der Gruppe zunahm. Manuskript III nimmt sich vier wertvollen Spannungen bei der Konzeptualisierung der "Professional Vision" und seiner Bezug zu kognitiven und soziokulturellen Perspektiven an: (a) die Art der didaktischen Unterstützungen, (b) die Art der Evidenzquellen, (c) die analytischen Methoden und (d) die Rolle materieller Repräsentationen (Téllez-Acosta et al., 2022a). Dieses Manuskript trägt dazu bei, den Wert der Bemühungen einer soziokulturellen Perspektive des Lernens für die Lehrer\*innenbildung zu erkennen und zu erweitern. Der Schwerpunkt liegt hauptsächlich auf das Design von Lernumgebungen und der Untersuchung des Lernens, um die untrennbare Beziehung zwischen angehende Lehramtsstudierenden, die professionelles Wissen aufbauen (gemeinsames Verständnis), und den sozialen und physischen Ressourcen in diesen Lernumgebungen zu berücksichtigen.

#### Abstract

The current dissertation work is two-iterative-cycle Design-based Research (DBR). It aims to design, implement, and analyze pedagogies and their associated pedagogical tools to support pre-service elementary teachers in learning to plan modeling-based investigations (MBIs). This kind of planning MBIs emphasizes engaging students in modeling as scientific and epistemic practice. This practice consists of co-constructing understandings that integrate disciplinary core ideas with the modeling process while investigating natural phenomena. Through MBIs, it is possible to engage students in scientific modeling as a sense-making iterative process in which they develop explanatory models based on what they learn from their investigations.

Planning MBIs entails two main challenges for pre-service elementary teachers. First, they are increasingly using science content resources, like online videos, to help them understand disciplinary core ideas. However, these videos do not directly allow them to epistemically experience how these ideas can be integrated with the practice of scientific modeling. Second, they typically do not have the pedagogical experience to approach these disciplinary core ideas to structure and sequence MBIs for students to learn disciplinary core ideas as they develop explanatory models of natural phenomena under investigation. To date, empirical studies in science teacher education have formulated designs, including different pedagogies and pedagogical tools, that provide opportunities for pre-service teachers to address these challenges. The focus has been on pre-service teachers acquiring knowledge of scientific ideas, modeling, and models or participating in the modeling practice. However, none of these cases has investigated how pre-service teachers negotiate epistemic and pedagogical meanings through discourses to build their professional understandings.

In order to contribute to filling this gap, the dissertation work's central argument is around designing practice-based learning environments with pedagogies and associated pedagogical tools, embedding a biology-specific epistemic tool. This design might potentially support pre-service elementary teachers' in-the-moment negotiation of epistemic and pedagogical meanings through discourse to learn how to plan MBIs. The focus on discourses to negotiate meanings is critical for the science teacher education field because discourses are a learning way from a sociocultural perspective of learning. Discourses emerge and change as pre-service teachers interact with social and physical resources.

In this sense, the dissertation work addresses pre-service elementary teachers' learning as developing a professional vision (PV) specifically from its foundation (Goodwin, 1994). Learning entails pre-service elementary teachers developing a PV for planning MBIs rather than acquiring pre-determined knowledge or skills regarding science, scientific modeling, or planning MBIs. Pre-service teachers learn by negotiating a PV that consists of negotiating epistemic meanings to understand that specific disciplinary core ideas (e.g., biology) and scientific modeling practice are integrated instead of competing goals. In addition, this PV consists of negotiating pedagogical meanings to structure and sequence the instruction in the form of MBIs to guide and sustain students' learning throughout an investigation of natural phenomena.

Aligned with the DBR approach and given the emphasis on pre-service elementary teachers' learning as discourses change, the dissertation work capitalizes on qualitative methods to design and study how they learn to plan MBIs. DBR highlights the theory-based design of learning environments as research contexts and the constant analysis of processes within those contexts to improve the design and implementation. The dissertation work develops in the context of a science teaching course for elementary school at a German university. This context

is suitable because it aligns with a practice-based standpoint encouraging pre-service elementary teachers' learning when working together. During the course, they learn within large and small group discussions (e.g., lectures and seminars) about different scientific core ideas of the major disciplines (e.g., physics, chemistry, biology, and earth sciences). At the same time, they learn how to approach these ideas integrated with scientific modeling by planning MBIs.

Professional vision (PV, Goodwin, 1994) is used as the theoretical and analytical framework to interpret pre-service elementary teachers' learning during the two iterative cycles. The three discursive practices of this framework, namely highlighting, coding, and material representations (MR), serve as the lens to analyze pre-service teachers' discourses. These discourses are ways of talking and acting to negotiate meanings when socially participating in the pedagogies and interacting with the pedagogical tools within the designed practice-based environment.

The results of the dissertation work are consolidated in three manuscripts. The first empirical manuscript (manuscript I) expands the findings of the first iterative cycle. Manuscript I focuses on studying how pre-service elementary teachers negotiate meanings around disciplinary core ideas, modeling, and planning MBIs for their future students while working with the provided support (i.e., pedagogies and pedagogical tools). The central contribution to science teacher education that emerged from this first study is that the biology-specific epistemic tool (Transformation Boxes, TBs) embedded in the pedagogies and associated pedagogical tools fostered pre-service teachers' flexibility in dealing with disciplinary core ideas and scientific modeling (i.e., pedagogical negotiation). This TBs tool also opened possibilities for structuring MBIs (i.e., pedagogical negotiation). Upon the base of this first cycle, the pedagogies and associated pedagogical tools were re-designed for the second iterative cycle. This re-design was carried out considering two main criteria: (a) re-structuring the pedagogies to increase the saliency of the aspects of planning MBIs and (b) simplifying the pedagogical tools towards more productive discourses (i.e., discussions that help make sense of more specific aspects of the practice). The second iterative cycle studied how pre-service elementary teachers, when negotiating meanings around planning MBIs, comprehend the twofold aim of this practice: epistemic and pedagogical. The main findings from this second cycle correspond to another empirical manuscript published as a book chapter (manuscript II) and a theoretical manuscript (manuscript III).

Manuscript II focuses on studying how pre-service elementary teachers learn to plan MBIs in a practice-based blended learning environment in which the re-designed pedagogies and associated tools were articulated as "Multimedia-Tools" in the management system ILIAS®. The "Multimedia-Tools" were organized using different web-based resources available (e.g., forums, blogs, and Etherpads), which have the potential to support pre-service teachers' professional learning through written discourses. The main contribution of this study to the science teacher education field is that a goal-oriented combination of web-based resources tasks.

Manuscript III approaches four valuable tensions in conceptualizing the PV framework and its relation to cognitive and sociocultural perspectives: (a) the nature of pedagogies, (b) the kind of evidence sources, (c) the analytical methods, and (d) the role of material representations. This manuscript contributes to recognizing the value of a sociocultural perspective of learning to expand teacher education efforts. Mainly, the emphasis is on the design of learning environments and the study of learning to consider the inseparable relationship between pre-service teachers building professional knowledge (shared understandings) and the social and physical resources within those learning environments.

#### 1. Introduction

In the science education field, there is an increasing emphasis on the scientific practice of modeling and models as critical parts of science learning at school. For instance, in the framework for K-12 science education (NRC, 2012), the Next Generation Science Standards (NGSS Lead States, 2013), the educational standards in the subject of biology for the middle school leaving certificate (KMK, 2005) or the analytical framework for PISA (Programme for International Student Assessment of the Organisation for Economic Co-operation and Development; OECD, 2018).

In the dissertation work, modeling is seen as a scientific and epistemic practice. Scientific modeling helps students understand how and why something happens in the world using specific disciplinary core ideas (Passmore et al., 2017). When engaging students in scientific modeling, they can make sense of the natural phenomena by developing models while co-constructing their understanding of the practice and disciplinary core ideas (Acher, 2014; Manz, 2012; Shim & Kim, 2018). This engagement also allows students to understand the nature and purpose of models, involving them in a meaningful practice in which they understand what they are doing and why they are doing it (metamodeling knowledge, Schwarz et al., 2009). Models are thus sense-making tools that mediate between natural phenomena (what is perceived) and the disciplinary core ideas that can be used for explaining or predicting the ongoing processes in those phenomena (Acher, Arcà, & Sanmartí, 2007; Louca & Zacharia, 2019).

At school, teachers can encourage and sustain students to develop models and use them as sense-making tools for explaining phenomena through modeling-based investigations (MBIs; Campbell et al., 2019). MBIs emphasize teaching practices such as planning, enactment, and debriefing upon the basis that engaging students in scientific modeling is an iterative process (Schwarz et al., 2009). It also implies that models change based on what students learn from their investigations about the phenomenon, disciplinary core ideas, and the modeling practice (Lehrer & Schauble, 2012).

Planning complex practices such as those MBIs is still difficult for in-service teachers (Miller & Kastens, 2018) and even more for pre-service teachers (Karlström & Hamza, 2021; Windschitl et al., 2012). Planning is a core or high-leverage teaching practice at the basis of teachers' professional work that aims to provide the structure and sequence for students to learn disciplinary core ideas as they participate in scientific practices such as modeling (Windschitl et al., 2018). This planning poses two central challenges, especially for pre-service elementary teachers, who typically are still developing an understanding of disciplinary core ideas and scientific modeling in their professional learning process. First, pre-service elementary teachers often feel unsure about their science content knowledge (Gunckel, 2013; Zembal-Saul, 2018). They also often lack experience with how this knowledge is generated via scientific practices such as modeling (Windschitl & Thompson, 2006). Although they can learn about the disciplinary core ideas using science content resources, like online videos (Baltaci-Goktalay & Ozdilek, 2010; Beach, 2020), it does not suggest that they can understand that these ideas are integrated with the practice of scientific modeling. Therefore, they likely continue to see scientific ideas and practices as competing learning goals to be achieved during science units (Berland et al., 2015).

Second, as novices, pre-service elementary teachers typically do not have experience planning how students can engage in investigation-based science (Kademian & Davis, 2018). For instance, for pre-service elementary teachers to learn how to plan MBIs, it is relevant that they learn three critical components: (a) clearly define natural phenomena, (b) frame modelingbased questions students can investigate, and (c) establish a coherent sequence of activities as the stages of MBIs (Benedict-Chambers et al., 2017; Louca & Zacharia, 2012). Through these three components, it is possible to arrange the conditions of investigations in which students are involved in ""getting a grip" on the material world to participate in the development of means to answer their inquiries" (Lehrer & Schauble, 2012, p. 717).

Research in science teacher education has emphasized designing practice-based learning environments as an effective way to support pre-service teachers in learning complex teaching practices like planning MBIs (Forzani, 2014; McDonald et al., 2013). Different empirical studies have highlighted the importance of designs that support pre-service teachers in developing knowledge of scientific ideas, models, and modeling to prepare them for their future teaching practices (Carpenter et al., 2019; Danusso et al., 2010; Yenilmez Turkoglu & Oztekin, 2016). Yet little is known about pre-service teachers' negotiation of meanings around scientific ideas, models, and modeling explanatory models as part of their learning to plan MBIs. The dissertation work assumes this is a negotiation of epistemic meanings, which considers integrating disciplinary core ideas and scientific modeling. This negotiation is necessary to prepare pre-service elementary teachers to guide students' engagement in scientific modeling toward co-developing understandings of discipline-specific core ideas and how these ideas are generated in the developing models (Acher et al., 2007; Manz, 2012; Ryu et al., 2015).

Other empirical studies that have examined pre-service teachers' professional learning for modeling-based teaching have stressed designs that support them in developing models to decide pedagogically how to incorporate scientific modeling into their lesson plans (Kenyon et al., 2011; Windschitl et al., 2008). However, this pedagogical decision-making has not been considered associated with pre-service teachers' in-the-moment negotiation of meanings around planning MBIs for their future students. Typically the focus has been on supporting pre-service teachers' individual professional knowledge or competence for modeling-based teaching (Göhner & Krell, 2020; Günther et al., 2019). The dissertation work highlights the importance of designs that support pre-service teachers to build that professional knowledge through their social and authentic participation in the teaching practice of planning MBIs (Grossman et al., 2009; Janssen et al., 2015). This participation means that they are provided with opportunities to enact this planning as a "real" teaching practice by socially negotiating pedagogical meanings through discourse (around defining natural phenomena, framing modeling-based questions, and establishing a coherent sequence of activities).

In this perspective, the dissertation work argues that designing practice-based learning environments with teacher education pedagogies and associated pedagogical tools, which embed a discipline-specific epistemic tool for biology, has the potential to support pre-service elementary teachers in planning MBIs. These pedagogies and pedagogical tools support pre-service elementary teachers' in-the-moment negotiation of epistemic and pedagogical meanings through discourse. Discourses are seen as a way of learning, including ways of talking and acting for particular purposes situated in and changing depending on situations within and across contexts (Kelly, 2017; Wickman & Östman, 2002).

Given this emphasis on preparing pre-service teachers in planning for modeling-based teaching as they negotiate epistemic and pedagogical meanings through discourse, the dissertation work sees their learning from a sociocultural perspective, specifically from the PV foundation (Goodwin, 1994). In this case, learning entails pre-service elementary teachers developing a PV for planning MBIs. It means pre-service elementary teachers negotiate epistemic and pedagogical meanings to build professional knowledge or, more specifically, shared understandings. Through negotiating epistemic meanings, pre-service teachers learn to see that disciplinary core ideas and scientific modeling practice are not competing but

integrated goals. Through negotiating pedagogical meanings, they learn to see that structuring and sequencing the instruction to guide and sustain students' learning targets these integrated goals while students develop explanatory models throughout an investigation of natural phenomena or MBIs.

Teacher educators have developed pedagogies to support pre-service teachers' participation in teaching practices by "doing," allowing them to plan, enact, and debrief in a way analogous to their future role (McDonald et al., 2014). Through these teacher education pedagogies, pre-service teachers can negotiate meanings as they "do" teaching, participating in the teaching practice of planning MBIs. In order to enhance pre-service teachers' professional learning while "doing" teaching, there have been studies in science teacher education on how different pedagogical tools or scaffolds support pre-service teachers learning to plan to facilitate students' engagement in scientific practices (Evagorou et al., 2014; Fick & Arias, 2020; Kademian & Davis, 2018). These tools serve as resources with which pre-service teachers can interact to help them negotiate epistemic and pedagogical meanings when learning to plan MBIs.

The dissertation work was developed under a DBR approach (Design-based Research; DBR Collective, 2003). It aims to design, implement, and analyze teacher education pedagogies and their associated pedagogical tools to support pre-service elementary teachers learning to plan MBIs while using online video resources. A practice-based learning environment was designed in the context of a course for teaching science at a German university located in the state of Sachsen-Anhalt. The design emphasizes three main elements: (a) articulation of three authentic and situated teacher education pedagogies to support elementary pre-service teachers negotiating pedagogical meanings while participating in the three critical components of the planning practice components (i.e., clearly define natural phenomena, frame modeling-based questions, and establish a coherent sequence of activities as the stages of MBIs), (b) use of pedagogical tools with prompts in the form of open-ended questions and visual representations to support the emergent processes of pre-service elementary teachers while working collaboratively within a group and, (c) embodiment of a discipline-specific (i.e., biology) epistemic tool within those pedagogical tools to support elementary pre-service teachers negotiating epistemic meanings while participating in the modeling practice.

The dissertation work's main conjecture is that with this design, elementary pre-service teachers would engage in discourses to negotiate their PV for planning MBIs. Goodwin's PV and its three discursive practices, namely highlighting, coding, and material representations, is used as a theoretical framework to analyze those discourses. The analysis aims to characterize pre-service elementary teachers learning to plan MBIs with the support of the designed learning environment.

The remainder of the document will detail the theoretical framework (section 2), conceptual elements (section 3), research argument (section 4), the methodological approach taken on the dissertation work (section 5), and describe the products that result from this DBR project (section 6). In the Appendixes are included the reified pedagogical tools associated with the pedagogies of planning MBIs in which pre-service elementary teachers participated and some examples of data corpus and analysis.

#### 2. Theoretical Framework

#### **2.1 Professional Vision**

In general, for characterizing learning, it is possible to explore cognitive or sociocultural perspectives (Danish & Gresalfi, 2018). From a cognitive perspective, the focus is on learners' individual mental processes and interests, their ability to use or transfer knowledge in certain situations, and the independence of those mental processes and interests from the contexts where they are developed. From a sociocultural perspective, the focus is on learners' participation in social practices, the transfer of this participation to other situations or overlapped practices, and the inseparable relation of the ways in which learners participate with the practices of the context.

With a focus on pre-service teachers' learning within practice-based environments, this dissertation work considers their professional learning from a sociocultural perspective. This choice is grounded in the assumption that pre-service teachers build and use professional knowledge as resources in specific learning contexts instead of having or lacking predetermined knowledge (Gray et al., 2021). Pre-service teachers' learning is beyond what can be assessed with standardized instruments, in which researchers establish the knowledge required for teaching. Instead, this learning emerges from their participation in teaching practices, negotiating meanings through discourses using their ideas and experiences while interacting with social and physical resources. As Gray and colleagues (2021) state: "we urge teacher educator colleagues to examine PST [pre-service teachers learning] in relation to the opportunities that are provided, or denied, in the preparation programs we design and enact" (p. 30). This is a reminder for teacher educators to study pre-service teachers learning for their teaching profession in relation to the features of the practice-based environments designed for them and not only if they meet or not predefined standards. From this sociocultural perspective, PV is an appropriate theoretical and analytical framework to interpret pre-service teachers learning through discourses while participating in the pedagogies and using their associated pedagogical tools. Goodwin's (1994) PV and its three discursive practices –highlighting, coding, and material representations- serve to analyze preservice teachers' discourses that emerge from their socially ongoing practice within a particular learning environment. "Within such a framework, the ability to see relevant entities is lodged not in the individual mind but instead within a community of competent practitioners" (Goodwin, 1994, p. 626). *Highlighting* involves making features of a domain salient by marking them somehow (e.g., pointing it out, using colored markers, expressing its relevance). *Coding* consists of providing meaning or transforming the relevant features into organized schemes related to the cultural practices of the profession. *Material representations* are artifacts that support the organization and persuasive display of relevant features of these professional practices.

These three discursive practices are the analytical lens to investigate how pre-service teachers negotiate and develop PV for planning MBIs within a practice-based learning environment. This dissertation work defines PV for planning modeling-based investigations as negotiating meanings around epistemic and pedagogical features to build professional knowledge, shared understandings of this kind of planning. Pre-service teachers' negotiation of epistemic meanings leads them to see that disciplinary core ideas (e.g., in biology) and scientific modeling practice are not competing but integrated goals. Meanwhile, their negotiation of pedagogical meanings leads them to see that structuring the instruction to guide and sustain students' learning targets these integrated goals while students develop explanatory models throughout an investigation of natural phenomena.

#### 2.2 Discourses to develop a professional vision

The PV framework from the sociocultural foundation of Goodwin (1994) sheds light on conceptualizing and analyzing learning through discourse as a social construction within a particular context (Ozcelik & McDonald, 2019). Learning is then a dynamic process where meanings are construed through discourses, which emerge and change in encounters between individuals and between individuals and the world (Wickman & Östman, 2002). This way of conceptualizing and analyzing pre-service teachers' learning as discourses is relevant for the dissertation work because discourses are seen as ways of talking and acting for particular purposes situated in and changing within and across contexts (Kelly, 2014). This stresses the importance of supporting pre-service teachers within university courses to engage in discourses to build shared professional understandings. In addition, it encourages researchers to study how those discourses lead pre-service teachers to shape meanings around their roles as students and future teachers and help them notice and manage conflicts emerging from the particular situations of different contexts (Gunckel, 2013; Thompson et al., 2015).

In general, studying pre-service teachers' discourses has been central for researchers to characterize how it is that they learn for their profession within specifically designed learning environments. For instance, researchers have studied pre-service teachers' learning from their discourses that resulted from their engagement in scientific practices. Windschitl et al. (2008) investigated pre-service teachers' epistemic discourses around modeling-based inquiry through university coursework, including learning activities based on a set of principles (heuristics for progressive disciplinary discourse). Through engagement in principle-based modeling experiences, pre-service teachers appropriated in various degrees more sophisticated epistemological views of the role of models, theory, evidence, and argument in scientific inquiry. Couso and Garrido-Espeja (2017) studied the discourses of pre-service elementary teachers when constructing a model through small-group laboratory-based discussions. In this

study, a designed learning environment based on a six-phase modeling cycle supported preservice teachers' discussions to learn about the modeling practice and move to complex versions of their models. Grimes et al. (2019) studied pre-service teachers' discourses as they developed an explanation of a complex phenomenon. This study fostered pre-service teachers' productive disciplinary engagement in the context of a course in the second year of a teacher degree program (engaged them in sense-making and argumentation processes). Engaging preservice teachers in this productive way led them from a generative discourse, expressing and sharing their ideas, to a normative discourse, a form of convergent argumentation with less instructor influence and more authority and responsibility of pre-service teachers.

In this context, the dissertation work highlights that pre-service teachers' engagement in discourses as they participate in the teaching practice of planning MBIs is their learning way (i.e., the way of developing PV). Discourses are the enacted forms of participation in social interaction for meaning-making and ways of taking advantage of the available resources (Ludvigsen & Nerland, 2018). As these authors stated, "It is through social interaction that knowledge resources are invoked, made sense of, explored, and further developed" (p. 154). Through discourses, pre-service teachers negotiate their PV for planning MBIs to co-construct understanding and shared meanings as they interact with a designed learning environment's social and physical resources. In this sense, PV is the theoretical and analytical framework that characterizes pre-service teachers' learning as discourses around planning MBIs. These discourses emerge and change in practice-based environments as pre-service teachers participate in teacher education pedagogies and use pedagogical tools.

#### 3. Conceptual elements and literature review

#### **3.1 Scientific modeling**

Consistent with student-centered reform-based science teaching (e.g., KMK, 2005; NRC, 2012; OECD, 2018), the dissertation work focuses on scientific modeling models as critical aspects of learning sciences. There is an increasing emphasis on modeling as scientific epistemic practice, considering that students are capable of engaging in knowledge-building processes (Krajcik & Czerniak, 2014; Lo, 2016; Louca & Zacharia, 2015; Passmore et al., 2017). This is instead of students merely acquiring isolated ideas about the discipline and scientific modeling (definitions, concepts) or reproducing a process without understanding its purposes.

As an epistemic practice, scientific modeling means engaging students in co-developing or integrating disciplinary core ideas with iterative cycles of constructing, evaluating, and revising models to make sense of natural phenomena (Acher et al., 2007; Manz, 2012; Ryu et al., 2015). This epistemic practice also includes understanding the purpose and nature of models (metamodeling, Schwarz et al., 2009). In this case, students' modeling practice implies that they are meaningfully engaged in a process where they clearly understand their work's purposes and how and why they engage in it (their epistemic considerations, Berland et al., 2015; Ke & Schwarz, 2019). Meaningful engagement refers to students using their ideas (about the practice, the content, or their experiences) to support their work in constructing mechanistic understandings of natural phenomena and doing it because these ideas are deemed to be helpful to that goal (Berland et al., 2015).

Scientific modeling is then considered a "domain-general" epistemic practice. It is possible to engage students in developing explanatory models in multiple scientific disciplines (e.g., the major disciplines of physics, chemistry, biology, earth, and space sciences). However,

discipline specificity is needed in the epistemological modeling process; therefore, scientific modeling is also "domain-specific." This domain specificity means that only specific disciplinary core ideas can satisfactorily help recognize and interpret the entities and the relationships that explain the ongoing processes in natural phenomena (Sezen-Barrie et al., 2020). This is based on the fact that each discipline has its own way of addressing the problems and engaging in practices to produce conceptual foundations (Ruppert et al., 2019). Ruppert and colleagues (2019) point out the need to continually support students in understanding the modeling practice and the associated domain-specific knowledge. For instance, as they found, "students included a variety of domain-specific ideas in their models, and these ideas served different roles in the model (delineating entities, activities, properties of entities, etc.)" (p.942). This research suggests that domain-specific knowledge is clearly linked to the domain-general practices, such as providing mechanistic explanations and the inclusion of evidence, and that it is relevant for teachers to help students understand these practices tied to the ideas of the discipline.

With this domain specificity focus, models are constructed as concrete representations consistent with specific disciplinary core ideas and the features of natural phenomena (Campbell et al., 2019; Shim & Kim, 2018). In order to improve their explanatory potential and match defined goals, models are evaluated and revised using empirical evidence or theory (Louca & Zacharia, 2012). In this context, models in the form of drawings and written or verbal statements are considered tools for epistemic purposes, particularly for explaining natural phenomena by using domain-specific ideas. There is consensus in the modeling literature that in order to be explanatory, models need to go beyond a mere description of the processes underlying a phenomenon to account for the mechanisms involved (Ke & Schwarz, 2021; Zangori & Forbes, 2016). Therefore, this dissertation work emphasizes mechanistic

models/explanations in which understandings of specific disciplinary core ideas are integrated to unpack causal chains in ongoing processes in natural phenomena.

#### 3.2 Modeling-based investigations

In order to engage students in scientific modeling as epistemic practice, teachers structure science units so that students engage in forms of inquiry or MBIs, where they can question and develop their interpretations of natural phenomena (Campbell et al., 2019). Students' engagement in MBIs depends on their agentic role, how they perceive the phenomena, their questions, and the purposes they define to move toward the desired outcomes (Miller et al., 2018). These desired outcomes are epistemic goals, not separated concepts or practical competencies but integrated understandings (Sezen-Barrie et al., 2020). Specific disciplinary core ideas co-develop or are integrated with understanding how and why these ideas are generated, for example, through engaging in the epistemic practice of developing explanatory models (Acher et al., 2007; Manz, 2012).

This co-development or integration of specific disciplinary core ideas into explanatory models suggests moving science teaching at school from focusing on students having or no knowledge of scientific concepts or practices to students using these ideas purposefully (i.e., to explain a phenomenon) to build their understanding (Campbell & Fazio, 2020; Forbes et al., 2019; Schwarz et al., 2017). Therefore, the dissertation work refers to modeling-based instead of model-based investigations, emphasizing three main aspects: (a) disciplinary core ideas are "big ideas" and no isolated concepts or topics from curriculum materials, (b) modeling is a process and not a finished form of knowledge and, (c) modeling is a collaborative endeavor.

MBIs concentrating on big ideas is essential to promote students deep learning as they participate in tasks that engage them in scientific practices (Kang, 2017; Windschitl et al., 2018). In this way, students learn the connections between concepts and principles and can use

this understanding for different purposes (Krajcik & Czerniak, 2014). Additionally, in MBIs, scientific modeling is an iterative process that unfolds as students investigate phenomena (Schwarz et al., 2009). The models developed across this process change based on what students learn from their investigations about the phenomenon, disciplinary core ideas, and the modeling practice (Lehrer & Schauble, 2012).

MBIs also emphasize students' collective engagement in scientific modeling, working with social and other resources. By engaging students in MBIs, "Students are accountable for describing their question, explaining what they have learned so far (including evidence to support claims), reporting any difficulties encountered, and appealing for help from the larger student group" (Lehrer & Schauble, 2012, p. 721). This highlights the role of discourses and social interaction at schools during science units for building and debating knowledge (Schwarz et al., 2017). "As students come to learn science concepts and engage in scientific practices, they develop more expansive ways of speaking, listening, and interpreting the discourse of science and can be viewed as communicatively competent with members of a relevant community" (Kelly, 2014, p. 323).

It is well documented how forms of inquiry or MBIs encourage students' collective engagement in modeling through discourse, providing them with opportunities to think and talk scientifically about natural phenomena (e.g., Hernández et al., 2015; Louca & Zacharia, 2015; Louca & Zacharia, 2019; Shim & Kim, 2018). For instance, Louca & Zacharia (2015) investigated how groups of elementary students engage in classroom discourses around modeling while using the Stagecast Creator (a software that supports the construction of symbolic models/simulations). This study stresses young students' discourses during wholeclass and small-group work to expand their cognitive processes (e.g., analyzing, synthesizing) and media used (e.g., paper-and-pencil or computer-based models) associated with scientific modeling.

In the case of secondary students, Shim & Kim (2018) explored how eighth-graders engage through discourse in six modeling lessons designed to help groups collaboratively develop models by discussing scientific ideas and evidence. The focus on students' discourses allowed them to see students' productive or unproductive participation in scientific modeling depending on their epistemological and positional framing. With productive framing, students found ways to contribute to the groups' knowledge-building processes, whereas with unproductive framing, they perceived their contribution was not needed or relevant for the process.

These studies in elementary and secondary students' modeling practice through forms of inquiry or MBIs serve to emphasize the importance of promoting students' agentic role, using and discussing their ideas meaningfully and productively as they interact with others and the available recourses. This meaningfulness means that students' engagement in MBIs is guided by their co-constructed understandings that integrate specific disciplinary core ideas with scientific modeling, which align with their sense-making goals of phenomena under investigation (Ke & Schwarz, 2021). Meanwhile, productivity means that students develop their models by socially discussing specific disciplinary and phenomenological aspects that help make sense and represent causal mechanisms of phenomena (Berland & Crucet, 2016; Engle & Conant, 2002; Forman et al., 2014).

#### 3.3 Planning modeling-based investigations

Planning is a core or high-leverage teaching practice pre-service teachers experience in learning to teach (Karlström & Hamza, 2019; Windschitl et al., 2012). For science teaching, the planning practice focuses on structuring and sequencing science units to engage and support
students' learning about disciplinary core ideas and how science works to construct and evaluate these ideas (Kademian & Davis, 2020). High-leverage means a practice that constitutes a priority in teachers' everyday work and that novices can learn as the foundation to continually build upon and refine other practices during their careers (Windschitl et al., 2012). There is consensus in science teacher education that the importance of planning stands as the starting point for novices to explicit and elaborate understandings of the target disciplinary core ideas and practices on which their future teaching is based (Beyer & Davis, 2012; Karlström & Hamza, 2021; McDonald et al., 2014). In addition, it is known that when planning, novices anticipate some of the ideas, experiences, or questions that students might bring to the classroom, which can be used as learning resources (Forzani, 2014).

Specifically, the dissertation work focuses on planning MBIs, defined as a core teaching practice consistent with ambitious forms of teaching (Windschitl et al., 2018). This practice consists of structuring science units to engage and support students in learning disciplinary core ideas and scientific modeling by investigating natural phenomena. The emphasis is on planning MBIs as science units (a set of related lessons) instead of single lessons. Science units suggest the systematic engagement of students in developing models throughout a coherent sequence and goal-oriented activities (Krajcik & Czerniak, 2014; Thompson et al., 2015).

This idea of planning for engaging students in MBIs throughout science units is consistent with recent research efforts to foster and support students' epistemic agency in the classroom (Berland et al., 2015; Gouvea & Passmore, 2017). Epistemic agency means that students are in charge of their practice, building scientific understandings in their classroom science practice communities (Stroupe, 2014). Miller et al. (2018) have examined four opportunities teachers may provide students in the classroom to position them with the epistemic agency, perceive themselves as epistemically agentic, and act with that agency: a) Opportunities to solicit and build on student knowledge as a resource for learning, b) Opportunities to build knowledge, c) Opportunities to build a knowledge product that is useful to students and d) Opportunities to change structures that constrain and support action (p. 1058). This emphasis on fostering students' epistemic agency serves to identify the critical components of planning MBIs that have the potential to appropriately structure science units in such a manner that students develop explanatory models of phenomena being epistemic agents, co-constructing knowledge, and understanding the nature and purpose of those models.

In this case, for planning MBIs that promote students' epistemic agency when engaging in scientific modeling, three critical components emerge as relevant: (a) clearly defining natural phenomena, (b) framing modeling-based questions students can investigate, and (c) establishing a coherent sequence of activities as the stages of MBIs (Benedict-Chambers et al., 2017; Louca & Zacharia, 2012). *Defining phenomena* at the earliest stage of structuring a modeling-based investigation serves to pose aims students will achieve throughout the unit (Campbell et al., 2019). It also presses students' to examine phenomena considering both observable and unobservable processes (Windschitl et al., 2008). *Framing modeling-based questions* is necessary to guide students to understand what they need to investigate (Passmore et al., 2017) and facilitate students' posing questions by themselves when developing models (Manz, 2012). *Establishing a coherent sequence of activities as the stages of MBIs* entails looking for students' engagement throughout investigations towards defined goals (Schwarz et al., 2017).

#### 3.4 Pre-service teachers learning to plan modeling-based investigations

The way of conceptualizing modeling as scientific and epistemic practice students can engage in has also influenced how teacher educators prepare pre-service teachers to plan MBIs. In this sense, the dissertation work positions pre-service teachers learning to plan MBIs as active agents participating in both the scientific practice of modeling and the teaching practice of planning MBIs for constructing rather than acquiring knowledge. When pre-service teachers participate in modeling as part of their learning to plan MBIs, they are provided with opportunities to negotiate epistemic meanings, including ideas of a discipline and modeling, while developing models to explain natural phenomena. As Kuhn et al. (2017) claim, "that deep engagement in science practice foster understanding of the epistemological foundations of science is of critical importance, rather than merely desirable" (p. 233). Pre-service teachers' participation in modeling is crucial considering that they increasingly use science content resources, like videos (Baltaci-Goktalay & Ozdilek, 2010; Beach, 2020) and need to understand how to epistemically approach this content integrated with the modeling practice for modeling-based teaching.

In addition to this epistemological participation, when pre-service teachers participate in planning MBIs, they can negotiate pedagogical meanings around the three critical components of this teaching practice (i.e., clearly define natural phenomena, frame modelingbased questions students can investigate, and establish a coherent sequence of activities as the stages of MBIs). This helps them in their two-fold role as student teachers, working to fulfill teacher educators' expectations and as future professionals (Bannister, 2015; Gunckel, 2013). Pre-service teachers are responsible for their learning and authors of the ideas, who co-construct their resources, and are in charge of solving problems based on purposes of their own accord.

In supporting pre-service teachers planning to engage students in modeling as a scientific practice, studies have stressed pre-service teachers' modeling practice to decide pedagogically how to incorporate this practice into their lesson plans (Kenyon et al., 2011; Windschitl et al., 2008). For example, in their study, Kenyon and colleagues (2011) investigated pre-service teachers' experience in scientific modeling through four iterative

designs (i.e., activities and materials), which support them in achieving learning goals associated with scientific modeling. A key implication of this study is "provide opportunities for pre-service teachers develop all the key elements of teacher knowledge required for engaging students in scientific modeling—namely teachers' own metamodeling knowledge, their subject matter knowledge, and their [Pedagogical Content Knowledge] PCK for scientific modeling" (p.19). This implication is relevant to the dissertation work because it suggests designs teacher educators can develop and refine to support pre-service teachers' participation in modeling-based experiences. However, it is possible to add to this research by developing designs that support pre-service teachers' in-the-moment negotiation of meanings around modeling-based teaching, in this case, to build understandings of specific disciplinary core ideas, modeling and planning MBIs.

Other studies have stressed that supporting pre-service teachers learning for modelingbased teaching means helping them gain knowledge about scientific ideas, models, and modeling, so they are prepared to expand students' modeling competence or scientific knowledge (Carpenter et al., 2019; Günther et al., 2019; Yenilmez Turkoglu & Oztekin, 2016). The focus is on pre-service teachers' perceptions about models and modeling, not their participation in scientific modeling for teaching practices. For instance, in their study, Yenilmez Turkoglu and Oztekin (2016) investigated pre-service elementary teachers' understandings of scientific models by using an instrument and interviews with direct questions about the roles, characteristics, and use of models (e.g., "What is the purpose of models?, What can you do with models?"; p.236). The findings of this study illustrate that pre-service teachers had fragmented perceptions of models; some were naïve perceptions of models as representations; for example, models should be exact replicas of phenomena or serve materialistic purposes (i.e., only visual or three-dimensional representations). Other perceptions were informed and reflected their understanding of the multiplicity of models due to subjectivity, social and cultural context, and creativity involved in developing scientific models. These informed perceptions also reflect their understanding of models' dynamics (i.e., models change in the light of new findings/evidence). Although this study highlights the importance of pre-service elementary teachers' understanding of the role and nature of models for them to plan their lessons effectively, these understandings should emerge from using models for particular purposes within a context. This opens up the field to study how it is that pre-service teachers come to understand scientific modeling and the role of models in planning for modeling-based teaching through their participation in this scientific practice.

#### 3.5 Practice-based learning environments for pre-service teachers

Practice-based environments are designed by teacher educators to support pre-service teachers to participate more directly in teaching, enacting particular components of the practice that enable them to learn in, from, and through practice (McDonald et al., 2013; Windschitl et al., 2012). The dissertation work defines this practice as a construction pre-service teachers make in sociocultural interchange (Bannister, 2015). Like Windschitl and colleagues (2012), the dissertation work sees these practices as both a way of preparing teachers and concretions of the learning goals. These teacher education practices are the vehicle by which novices make concrete their participation in co-construction, collaborative dynamics of knowledge-building, and co-develop PV (Ozcelik & McDonald, 2019).

This stance towards teacher education practices as vehicles for pre-service teachers' learning is consistent with designing environments that support them in negotiating epistemic and pedagogical meanings when learning to plan MBIs. When pre-service teachers learn by socially participating in scientific modeling and planning MBIs, they develop understandings to support students' engagement in MBIs in their future teachers' roles (Davis, 2016; Ross & Cartier, 2015). Through pre-service teachers' participation in planning MBIs, they have the

opportunity to organize the content to teach not as individuals but as communities, in which they can enhance their professional learning (Wickman, 2012).

Building upon this sociocultural perspective of learning, in the dissertation work, the teaching practice of planning MBIs is a means for pre-service teachers to learn within a community and thus is the location and source of learning. While "doing" or participating in the activities of this practice, pre-service teachers engage in discourses to negotiate meanings around planning MBIs. Discourses are seen as the ways communities communicate, make sense of their experiences and interact with others to shape their ideas (Gunckel, 2013). In order to help pre-service teachers participate in the teaching practice of planning, not as a rote performance but deliberately within a community, it is possible to articulate teacher education pedagogies as supports. In this way, preservice teachers learn to approach the teaching profession as a social activity in the classroom and as peer collaboration (McDonald et al., 2013).

#### **3.6 Teacher education pedagogies as supports**

Recently teacher educators are using pedagogies to support pre-service teachers in learning to perform teaching practices (Davis, 2016; Ghousseini & Herbst, 2016; Tyminski et al., 2014). Grossman et al. (2009) identified three key concepts for understanding the pedagogies that prepare people for their professional practice: approximations, decompositions, and representations of practice. *Approximations of practice* have been used as authentic opportunities for pre-service teachers to engage in teaching practices. For example, Davis (2020) designed approximations of practice, including peer-teaching rehearsal, small-scale field-based teaching, and full teaching experiences, to provide a structure for pre-service teachers' work when enacting complex teaching practices. These approximations aimed to reduce the complexity of the practices by highlighting specific features and thus maintain pre-

service teachers' attention to particular goals. In addition, these approximations aimed to guide pre-service teachers to problematize their work, supporting their reflection on facing the complexity and making this work more interesting, productive, and non-trivial. Examples of these designs are essential to the dissertation work because they illustrate how teacher educators can provide pre-service teachers with practice-based experiences to manage the complexity of teaching practices in authentic ways. This authenticity means that pre-service teachers can enact "real" teaching activities, manage specific situations and thus gain the experience they need for future practice (Forzani, 2014).

Decompositions of practice are components of teaching practices that teacher educators use to help pre-service teachers see and enact these practices more effectively. Teacher educators may break down a teaching practice into its constituent components and build upon them approximations of practice through which pre-service teachers engage in teaching work. For example, Tyminski et al. (2014) used decompositions of teaching practices regarding mathematics education, namely strategy sharing, organizing whole-class discussion, and asking questions. In the case of the practice of asking questions, Tyminski and colleagues decomposed it into three types of questions (i.e., general, specific, and leading) in order to support pre-service teachers' ability to guide students throughout the lesson. When engaged in these decompositions, pre-service teachers learned to frame general questions to generate discussion among students or explore their mathematical ideas (e.g., Can you explain your solution for that problem?). They also learned to frame specific questions that address something in particular within students' explanations (e.g., When you explain X, why do you change Y by Z?) and leading questions to guide students towards particular goals (e.g., How could you do this, in order to get that?). From this example, the dissertation work takes that by decomposing the practice into its components, teacher educators make teacher practices

manageable for pre-service teachers as they are provided with a structure to identify and enact these components and then put them together to understand the whole practice.

Finally, *representations of practice* are how teacher educators make the relevant features of teaching practices visible to pre-service teachers. Danielson et al. (2018) have highlighted the use of representations in teacher education, including videos, case studies, templates, classroom transcripts, and observations, to help pre-service teachers see facets of the teaching activities and learn by discussing them. In this line of reasoning, the dissertation work considers that representations of practice carry more than their intended purpose (Grossman et al., 2009), and, therefore, pre-service teachers can use them to negotiate meanings around modeling-based teaching.

To sum up, the dissertation work aligns with the articulation of teacher education pedagogies in the form of approximations, decompositions, and representations of practice as supports for pre-service teachers learning to plan MBIs. This is consistent with authentic and situated ways of learning. Pre-service teachers' participation in pedagogies is authentic since they work close to the "real" practice and is situated since their understanding depends on the social situations they create within a learning environment. Through approximations of practice, pre-service teachers enact the high-leverage teaching practice of planning, assuming a teacher role, and establishing purposes for engaging students in MBIs. In addition, by providing pre-service teachers decompositions of practice that serve as the foci of planning, it is possible to guide them to "do" teaching, understanding how and why practicing each of the three critical components of planning MBIs contributes to the overall teaching practice. These pedagogies can also be used as representations of practice to help novices build professional understandings of planning MBIs through negotiations of meanings. In this perspective, tools that embody these pedagogies enhance how pre-service teachers participate in planning MBIs, engaging in discourses through which they negotiate meanings around this practice.

## 3.7 Tools and resources associated with teacher education pedagogies

Tools in science teacher education or pedagogical tools are physical or digital artifacts (e.g., videos, computer programs, paper-based objects, visual representations) that support preservice teachers in accomplishing particular tasks when learning to teach (Fick & Arias, 2020). The dissertation work advocates for pedagogical tools that can become part of pre-service teachers' activity and help them shape and negotiate their PV, specifically for planning MBIs. These tools also should incorporate discipline-specific epistemic tools that support pre-service teachers' negotiation of meanings, which integrate domain-specific disciplinary core ideas, modeling, and models.

#### 3.7.1 Pedagogical tools

The dissertation work builds upon the notion of pedagogical tools in the form of priming tools, as these enhance pre-service teachers' discourses to collectively build a language or understanding of the teaching practice that they learn (Thompson et al., 2013). *Priming tools* in the form of paper-based objects have been used to mediate pre-service teachers' initial attempts at teaching, helping them to structure the lesson (planning), preparing for discursive interaction with students (enactment), or for reflecting upon teaching (debriefing; Windschitl et al., 2012). One example of a priming tool proposed by Windschitl and colleagues (2012) is the Big Idea tool, a planning-focused tool. This tool was an electronic document designed to help novice teachers identify the big ideas to engage students in productive scientific conversations in the classroom. Big ideas are not curricular topics (e.g., photosynthesis, ecosystems) but are sets of interrelated concepts that help make sense of natural phenomena. The Big Idea tool consists of a series of questions (e.g., "What aspects of these [things/events]

might be relevant to kids' lives?") that prompt pre-service teachers to unpack the target ideas that are relevant for students to interpret the ongoing processes (observable and unobservable) in natural phenomena by answering how and why these processes happen.

From this perspective, the dissertation work takes as pedagogical tools the artifacts that represent the teaching practice, specifically the pedagogies of planning MBIs. For example, if a pedagogy comprises pre-service teachers' activities for establishing a coherent modelingbased sequence towards defined goals for their future students, a pedagogical tool can be a concrete form to work with within a group. This tool can contain questions such as: (a) Is the sequence appropriate for students? (b) What are the learning goals for each step of the sequence? These questions or other aspects in the tool foster pre-service teachers' discourses and mediate how meanings are negotiated to build understandings of planning MBIs in a designed practice-based learning environment.

Considering the relevance of pedagogical tools to offer pre-service teachers guidance and clarification when participating in planning how to support students' scientific learning, this dissertation work also acknowledges the importance of using tools of epistemic nature. Recent studies in science education have highlighted the value of epistemic tools to facilitate students' collaborative sense-making of natural phenomena, supporting how they engage in scientific practices leading to the co-construction of disciplinary knowledge and practices (Ke et al., 2020).

#### **3.7.2** Discipline-specific epistemic tools

The dissertation work's interest in using epistemic tools in preparing pre-service teachers for their future practice comes from considering science education as constructing meanings through social interaction via discourses (Settlage & Southerland, 2019; Sezen-Barrie et al., 2020). These discourses emerge and change in authentic social settings and where

what counts as knowledge is defined among members of a community (Kelly et al., 2012). In this respect, epistemic tools have been used as concrete forms such as visual representations, charts, rubrics, tables, maps, or physical models that support students' knowledge-building (Kelly & Cunningham, 2019).

The dissertation work focuses on epistemic tools that might support pre-service teachers to understand that planning is structuring science units toward engaging and supporting students in MBIs. MBIs help students build knowledge through co-development or integration of disciplinary core ideas and modeling. In this sense, domain-specific supports are necessary to aid this integration. These domain-specific supports have the potential to aid pre-service teachers (in the same way that they will aid students and teachers in the classroom) in linking scientific modeling as a "domain-general" and "domain-specific" (Ruppert et al., 2019). As a "domain-general" practice, scientific modeling is used to develop explanatory models of phenomena related to various disciplines (e.g., physics, chemistry, biology, earth, and space sciences). However, "[i]t is impossible to engage in any of these practices [within those scientific modeling] without at the same time addressing some domain of science and building an understanding of some science knowledge" (Osborne & Quinn, 2017, p. 31). Domain-specific modeling implies developing understandings that include knowledge about a content domain and how knowledge is generated within that domain (Manz, 2012; Ryu et al., 2015).

Different epistemic tools have been used to support students in developing understandings in specific domains. For example, Kelly & Cunningham (2019) examined elementary students' use of epistemic tools for engineering design, specifically for three critical practices: constructing models and prototypes, making trade-offs between criteria and constraints, and communicating through uses of conventionalized verbal, written, and symbolic modes. Ke et al. (2020) studied how high school students used epistemic tools such as the start chart and causal maps for systems thinking about socio-scientific issues. In these cases, the potential of epistemic tools stands in the support these offer students to develop shared understandings within the constraints of the contexts in which these are being used. The epistemic tools used in these studies (i.e., in engineering design and modeling practices associated with socio-scientific issues) helped students understand these practices and the scientific ideas related to those practices (e.g., ecosystems, food web, organisms, and homeostasis, respectively).

#### 3.7.2.1 Transformation Boxes. A biology-specific epistemic tool

By considering the relevance of engaging students in scientific modeling to co-develop or integrate specific disciplinary core ideas and practice (i.e., the link between domain-specific and domain-general modeling), the dissertation work emphasizes the use of a biology-specific epistemic tool. In a broader context, biology appears as one of the major fields (in addition to physics, chemistry, earth, and space sciences) needed for students to participate in modern societies (OECD, 2018). In particular contexts, for instance, in the elementary education curriculum of the Ministry of Education of the state of Sachsen-Anhalt in Germany (Ministerium für Bildung des Landes Sachsen-Anhalt [MBLS-A], 2019), the aspects related to biology disciplinary core ideas appear to have relevance for elementary school. In this case, it is central that students learn about their bodies, animals, plants, soil, and the interaction of living beings with their environment.

With this disciplinary focus, the biology-specific epistemic tool of Transformation Boxes (TBs; Acher & Arcà, 2020) is used in the dissertation work. This TBs tool focuses on students' interaction with it in a sociocultural setting, which positions students in practice analogous to that of the scientists to construct biology knowledge (Acher & Arcà, 2020). In this case, biology knowledge is seen not as isolated declarative statements (e.g., concepts and definitions) but as the integration of biology ideas (theoretical basis) and the modeling practice through which those ideas are generated. Although this TBs tool has been mainly used in school contexts, the discipline specificity and the interactive possibilities provided by the TBs tool are critical for supporting pre-service elementary teachers' learning. This firsthand experience of elementary pre-service teachers with epistemic tools allows them to participate in an epistemic process, building understandings of disciplinary core ideas and practices while offering guidance to be prepared to afford students' needs in the classroom (Settlage & Southerland, 2019).

The TBs tool is a biology-specific epistemic tool that provides a visual representational form to work with (Figure 1). The interactions with visual representations are crucial for collaborative negotiation of meanings and co-construction of shared understandings (Quillin & Thomas, 2015). A TBs represents any biological structure, either an entire organism or a structure inside an organism in continuous dynamic exchanges of matter, energy, and information with proximal or distant environments. Inside TBs, biological transformations of matter, energy, and information can happen, and their transformed forms are then exchanged with other TBs according to their biological functions or environments that emerged coconstructed due to these exchanges. Therefore, it is possible to interpret changes in natural phenomena as biological transformations through matter, energy, and information as epistemic dimensions. Matter refers to materials at observable (e.g., food) or unobservable levels (e.g., molecules). Energy is closely associated with the characteristics of the materials, and its many forms can also be considered as consequences of this characteristic at observable (e.g., movement) and unobservable levels (e.g., rupture of chemical bonds). Information refers to signals that guide and coordinate (triggers, stops, speeds up, or slow down) changes in matter and energy at the observable (e.g., perception through the senses) and unobservable levels (e.g., transfer of electrical or chemical signal between neurons or other cells). This three-dimensional

way of interpreting biological transformations is unique for biology as a discipline. It mirrors the epistemic work of biologists in understanding causes and effects in the multiple interactions of living things, parts of them with their surroundings through exchanges of matter, energy, or information (Lewontin, 2001).

**Figure 1.** Visual Representation of the Transformation Box Tool (TBs) Adapted from Acher & Arcà (2020).



The TBs tool in Figure 1, which focuses on biological transformations of matter, energy, and information, can be used iteratively in at least five different ways to develop mechanistic models/explanations of biological phenomena. A mechanistic model/explanation unpacks causal chains (i.e., the different relationships of components) in ongoing biological transformations to interpret and explain how a phenomenon works. TBs tool can be used to *differentiate observable and unobservable changes*. For example, for interpreting a natural phenomenon concerning a plant's blossoming during spring, the formation of flowers (observable) can be differentiated from changes of molecules inside the plant triggered by changes in sunlight intensity (unobservable). Then, TBs can be used to *associate changes with the biological structures where these changes occur*, and thus interpret these changes as biological transformations. The plant can be represented as a big TBs, and the blossoming can be interpreted iteratively as biological transformations within smaller TBs, like leaves, roots, and shoots. In addition, TBs can be used to *identify functions as unfolding biological* 

*transformations of matter, energy, and information.* For instance, the function of the leaves is to produce food (matter) for the plant through the biological transformation of sunlight (energy), carbon dioxide, and water (matter). Then, TBs can be used *to organize hierarchically and chronologically the dynamic fluxes of matter, information, and energy* that explain the relationships between the biological structures with the detail needed. In this case, to explain how all the plants' parts work together in the processes that result in blossoming.

Drawing upon this potential of the biology-specific epistemic tool of TBs, this dissertation work uses it as a central embodiment for articulating pedagogical tools associated with pedagogies to support pre-service elementary teachers in planning MBIs of biological phenomena. This is because through the TBs tool; it is possible to: (a) mediate the co-construction of knowledge through a visual representation, (b) interpret phenomena within the constraints of biology using three epistemic dimensions, and (c) provide five different ways of accounting form mechanisms in biological phenomena. To foster and mediate pre-service teachers' learning to plan MBIs through pedagogical and epistemic tools, teacher educators can capitalize on the potential of online tools and web-based resources. This is given the increased need to provide pre-service teachers with learning opportunities such as those in online environments that help minimize time and space learning constraints (Johnson, 2016).

#### 3.8 Online tools and web-based resources

E-learning or online tools are forms organized through web-based resources such as forums, wikis, blogs, portfolios, etc., to facilitate and enhance pre-service teachers' participation in online learning environments (Banday, 2013). These web-based resources are mediators that enable communication, discussion, and collaborative work towards common goals (Chan & Yang, 2018). Recently, articulating online tools has increased importance to the

extent that it has become necessary to overcome pre-service teachers' time and space constraints to interact among them and with teacher educators (Johnson, 2016; Weller, 2013).

Given the characteristics of the context where the dissertation work is developed (a face-to-face course that can be complemented with resources in the ILIAS® learning management system), it focuses on articulating online tools as blended tools. From an inclusive conceptualization, blended learning tools are articulated to support participation in a combination of face-to-face and online activities, including the use of web-based resources and digital technology (Hrastinski, 2019). Research in this field encourages the design of blended learning programs that increase pre-service teachers' participation in collective knowledgebuilding processes, having clear the purposes for such processes (Geiger et al., 2018). For instance, in their study, Dini and colleagues (2021) designed a blended-online professional development program that combines face-to-face meetings, and a discussion board called the Community Forum within the InterLACE platform. The central contribution of this study is that "within an online mostly text-based medium [highly supported by the combination of faceto-face and online activities], learners can stably engage in sense-making practices and collaborate towards achieving epistemic goals" (p. 432). Although this study is not specific to modeling-based teaching, it is important for the current study as it relates to scientific engagement considering learners' epistemological dynamics (i.e., using scientific knowledge in scientific activity such as making sense of phenomena).

In summary, pedagogical tools embodying a biology-specific epistemic tool and enriched with online resources can enhance pre-service teachers' discourses for knowledgebuilding processes (i.e., constructing shared understandings). Pre-service teachers build knowledge by negotiating their professional vision for planning MBIs while participating in authentic and situated teacher education pedagogies. In this case, pre-service teachers are supported through pedagogies and associated pedagogical tools to build knowledge through discourses related to disciplinary core ideas integrated with the scientific practice of modeling and how to structure MBIs appropriately for their future students. A focus on discourses is central because, "through both online and offline discourse, students pursued idea improvement: they formulated problems of understanding, set forth theories to be improved, identified constructive information, and compared different ideas and models" (Chan & van Aalst, 2018 p. 300).

#### 4. Consolidated research argument

From the aspects above considered from the literature, the dissertation work's central point is designing practice-based environments with pedagogies and associated pedagogical tools embedding a biology-specific epistemic tool to support pre-service elementary teachers in planning MBIs. MBIs aim to provide an appropriate structure for students to engage in scientific modeling, constructing understandings of biology core ideas integrated into explanatory models of biological phenomena. Three main areas of research inform the project:

- (1) Teacher education pedagogies (approximations, decompositions, and representations of practice) are supports for pre-service elementary teachers to have authentic and situated opportunities to participate in teaching practices. In this case, pedagogies to participate in planning MBIs with a focus on critical components of this practice: (a) defining natural phenomena, (b) framing modeling-based questions, and (c) establishing a coherent sequence of activities as the stages of MBIs.
- (2) Pedagogical tools embedding the biology-specific epistemic tool of Transformation Boxes are concrete forms with which pre-service elementary teachers can work when negotiating meanings to build shared understandings about the integration of biology core ideas/modeling and structuring MBIs for their future students.
- (3) Pre-service elementary teachers learn by negotiating meanings through discourse. Therefore, the PV is a suitable framework to interpret their learning. PV for planning MBIs emerges from pre-service teachers' participation in teacher education pedagogies and is negotiated by interacting with others and the resources, including their ideas, experiences, and pedagogical tools.

#### 5. Methodological approach. Desing-based Research (DBR)

The dissertation work is situated in qualitative research (Creswell, 2012) as it aims to obtain a detailed interpretation of pre-service teachers learning in a discourse-focused manner. Given this focus on pre-service teachers' discourses emerging within a particular context, the study follows a design-based research (DBR) approach. Two main aspects characterize the use of this DBR approach in the dissertation work: (a) the design of learning environments as research contexts is guided by theoretical constructs that are developed and open to be refined, and (b) the ongoing and retrospective analysis of what happens within those environments for formulating and revising future designs and implementations (Cobb et al., 2009). DBR approach helps comprehend the relationships among conceptual elements, designed artifacts, and outgoing processes (e.g., discourses). This comprehension allows the generation of knowledge and educational practices to further innovative designs (Design-Based Research Collective, 2003).

The following sub-sections start with describing the dissertation work's context and the general design features based on Sandoval's (2014) conjecture mapping. Then a sub-section is dedicated to the details of each of the two iterative design, implementation, and analysis cycles, emphasizing the design elements in each case.

## 5.1 Context

The context was a science teaching course at a German university located in Sachsen-Anhalt state. The course lasted for three months and corresponded to the second semester for obtaining a teaching degree for elementary school. The entire course consisted of lectures (in which 100-120 pre-service elementary teachers participated) and seminars (in each of which there were twenty participants). During their program, pre-service teachers do not count on discipline-specific courses. Therefore, the course lectures were intended to help them learn about different scientific core ideas of the major disciplines (i.e., biology, physics, chemistry, and earth) and how to plan for approaching these ideas at school according to the current demands of science education. Weekly seminars aimed to engage pre-service teachers in practical activities related to the lecture's topics that they could perform in groups and with the teacher educator's guidance.

For the dissertation work, it was asked voluntary participation of the groups that, during the seminars, focused their practical activities on biology core ideas. The groups of three to five individuals were created independently by pre-service teachers considering their interest in working on a specific biology core idea. Each group selected the biology core ideas for their planning, considering the elementary education curriculum of the Sachsen-Anhalt state (MBLS-A, 2019). This was relevant because of their future teaching practice at school. The groups also used the Framework of K-12 Science Education (NRC, 2012) to identify life science core ideas related to biology in Sachsen-Anhalt's elementary education curriculum. This was part of the groups' acknowledgment that their planning should focus on covering core ideas instead of disconnected topics. The central core ideas worked by the groups were: (a) Structure and Function, (b) Organization for matter and energy flow in organisms, (c) Information processing by organisms, (d) Interdependent relationships of organisms in ecosystems, and (e) Ecosystems dynamics, functioning, and resilience.

Figure 2 details the features of the DBR project. These features are described based on Sandoval's conjecture mapping (2014) and are informed by the dissertation work's main conceptual aspects or research areas. The conjecture map of the project (Figure 2) starts with a high-level conjecture that drives the two iterative cycles and constitutes the central hypothesis about how to support the desired form of learning. It was conjectured that a practice-based learning environment, including pedagogies and pedagogical tools, might support elementary pre-service teachers in planning MBIs. The high-level conjecture was reified into four embodiments or design elements: tools, task structure, participant structure, and other resources. In this case, the tool refers to the biology-specific epistemic tool of TBs. The task structure corresponds to the pedagogies focusing on critical components of planning MBIs. These pedagogies establish the tasks pre-service teachers are expected to enact and their goals. The participant structure refers to groups of pre-service teachers participating in the pedagogies while interacting with the corresponding pedagogical tools. Resources include science content online videos, and web-based resources that are also intended to support pre-service teachers learning to plan MBIs.

**Figure 2.** Conjecture Map with Features of a Design to Support Pre-service Elementary Teachers to Plan MBIs



The four elements that embodied the designed learning environment (i.e., the epistemic tool of TBs, the tasks and participants' structure, and the resources) were designed to work together to generate mediating processes. These mediating processes are central because, as Sandoval (2014) states, "*processes* emphasize the process–outcome link of concern to design

research" (p. 23). In this dissertation work, pre-service elementary teachers' discourses, including the material representations that they created and used (i.e., explanatory models and planning artifacts), are the mediating processes that emerge in the implementation phase. Through these discourses and material representations, meanings are being negotiated to produce the desired learning outcomes. In this case, the outcomes of PV for planning MBIs: shared understandings of biology core ideas integrated with the development of explanatory models and how coherently and appropriately structure and sequence MBIs to engage and support students learning.

The embodiments or design elements (i.e., the epistemic tool of TBs, the tasks and participants' structure, and the resources) remained across the two iterative cycles as the dissertation work's aim of supporting pre-service elementary teachers in learning to plan MBIs persisted. However, according to DBR methodological approach, the first cycle's theoretical and practical contributions were identified for re-designing, implementing, and analyzing the second cycle (See yellow and orange boxes in Figure 2). Table 1 shows the differences between the two iterative cycles.

The main difference was that groups worked face-to-face during the first cycle, whereas, in the second cycle, there were groups working face-to-face and others in a blended online learning environment. Despite the differences in the learning environment features in the second cycle, the aim was not to compare learning outcomes. Instead, the emphasis was given to how features of each environment enable or constrain the mediating processes (i.e., discourses for negotiating their PV for planning MBIs) expected of pre-service teachers. The following sections describe each cycle, considering the specific focus of each study.

Iterative	Iterative Design Implementation				
cycle		Participants	Setting	Data Collection	
1	Three pedagogies and their associated pedagogical tools around the biology-specific epistemic tool of TBs and focused on a critical component of planning MBIs.	Twenty-four pre- service elementary teachers (6 groups)	<ul> <li>Each group of pre-service teachers met separately during three face-to-face sessions.</li> <li>During each session, they enacted one of</li> </ul>	•Video recordings •Material representations created while video recorded	Use the analytical lens of PV to characterize pre-service teachers' discourses
2a	Re-designed pedagogies and associated pedagogical tools	Fourteen pre-service elementary teachers (3 groups)	<ul> <li>the pedagogies and worked with the corresponding tool.</li> <li>Groups worked without the researcher or teacher educator intervention.</li> </ul>		
2b	Re-designed pedagogies and associated pedagogical tools articulated as Multimedia-Tools in ILIAS®	Fifty-eight pre- service elementary teachers (12 groups)	• Each group of pre-service teachers worked separately and independently in the online environment.	<ul> <li>Posts in the Forums and Etherpads.</li> <li>Data tables created by groups</li> <li>Material representations uploaded</li> </ul>	-

**Table 1.** Differences Between the First and Second Iterative Cycles

# **5.2 First iterative cycle**

This cycle focused on studying how groups of pre-service elementary teachers negotiate meanings around disciplinary core ideas, modeling, and structuring MBIs for their future students while engaged in each of the three pedagogies and with the support of the pedagogical tools.

**Design.** The design conjecture that guided this study was that groups of pre-service elementary teachers socially participating in the three pedagogies and using the associated pedagogical tools would engage in discourses to negotiate PV for planning MBIs.

*Tools*. The discipline-specific epistemic tool of TBs was used as the critical tool to support the negotiation of epistemic meanings to integrate biology core ideas into explanatory models of biological phenomena.

*Tasks structure*. As shown in Table 2 below, three teacher education pedagogies and their corresponding pedagogical tool were articulated, focusing on critical components of planning MBIs to support the negotiation of pedagogical meanings. The three key concepts for understanding pedagogies, namely approximations, decompositions, and representations of practice, were considered. Approximations of practice corresponded to the activities preservice teachers had to enact to achieve a common purpose that allowed them to experience an authentic planning practice. Decompositions of practice provided a structure that helped preservice teachers to see and enact those activities by suggesting a sequence of tasks. Representations of practice were grounded on the epistemic tool of TBs. The visual representation of TBs (Figure 1) was organized in many ways to support pre-service teachers in negotiating meanings around the development of explanatory models in each pedagogy.

**Pedagogies** Key concepts for understanding pedagogies **Decompositions of practice** Approximations of Representations of practice practice\* 1: Characterize • Define a Identify and characterize changes and Use the general 1. phenomenon (P). visual changes and stabilities in a phenomenon. Construct pairs of opposites (changesrepresentation of stabilities in Uncover changes 2. defining a /stabilities at stabilities) and evaluate their relevance to TBs to identify phenomenon different scales (E). examine the phenomenon upon aspects changes and of specific biology core ideas. stabilities

**Table 2.** Pedagogies Articulated Considering Three Key Concepts to Support Pre-serviceTeachers Learning to Plan MBIs

	• Frame a driving question, which guides and sustains students' work (P).	3.	Formulate a "how" question that poses an overarching problem to investigate, an overarching pair change-stability of the phenomenon.	
2: Develop an explanatory model via the biology-specific support of TBs uses and content videos	• Generate a robust model to explain the phenomenon (E). This model answers the driving question (P).	1. 2.	Analyze biology content resources (e.g., online videos) to identify biology core ideas' usefulness for interpreting the phenomenon. Create a concrete interpretative representation with a written explanation of the phenomenon that answers the driving question.	Use the general and a more elaborated visual representation in which TBs were organized to illustrate their various uses.
3: Design a coherent modeling-based instructional sequence	<ul> <li>Establish a sequence of intermediate questions (P).</li> <li>Generate partial models/explanations (E).</li> </ul>	1. 2. 3.	Develop a sequence of intermediate questions that constitute a coherent pathway for answering the driving question. Each question target specific features (changes-stabilities) of the phenomenon or the biology core idea. Create a concrete interpretative representation with a written explanation of the phenomenon's specific features that answer each intermediate question. Generate alternatives of partial models that address different aspects of the phenomenon.	Use an abstract representation of an explanatory model based on TBs

\* (E) Epistemic-directed goal, (P) Pedagogical-directed goal

*Participants structure*. Pedagogical tools with prompts in the form of open-ended questions, statements to discuss, and visual representations were provided. This was to facilitate that pre-service teachers within a group make visible their ideas and discuss them with particular purposes to build shared understandings. Figure 3 illustrates a part of the pedagogical tool that corresponds to the pedagogy to support pre-service teachers in developing an explanatory model via TBs and the content videos during the first cycle. Although it is not expected to see all the details in Figure 3, it highlights how the main design elements that supported pre-service teachers were reified into a paper-based object with two sections. Appendix A contains a complete version of the three pedagogical tools designed, implemented, and studied during this first iterative cycle. These tools contain what was expected from the group's work according to the conceptual elements considered in the design.

# **Figure 3.** Part of a Pedagogical Tool to Support Pre-service Teachers to Develop an Explanatory Model via TBs and Online Videos



As shown in Figure 3, the first section included tasks aligned with epistemic work via TBs (e.g., developing final and partial models/explanations) or the planning (e.g., formulating intermediate questions that can be answered with the partial/models explanations). These two kinds of tasks were overlapped considering a goal-directed enactment, so the groups could adequately go beyond the limits of the single activities (Kloser & Windschitl, 2020). The second section, called "before continuing," included prompts as open-ended questions and statements to be discussed. Those prompts aimed to support groups in considering essential steps or those needing to be attended to provide a sense of meaning in a task before continuing to the next (Reiser & Tabak, 2014). The visual representations based on TBs were expected to enhance the group's engagement in the tasks and the discussion within the group.

*Resources.* Online biology content videos were provided as resources to support understanding biology core ideas. It was expected that the videos help pre-service teachers focus on the biology core ideas they may need to develop their explanatory models. The videos were selected considering three main criteria. The videos came from reliable sources, developed by experts, and validated for a diverse community of users to ensure that the information was pertinent and accurate. These videos detailed organisms, different structures with various functions, and the substances involved in those functions, which are general ideas that the groups could use in their explanatory models. The videos also present examples and diagrams to give the groups a greater sense of familiarity with the biology core ideas and provide insights to include in their models. Although most of the videos fit the criteria, we expected that the groups would purposefully use them to develop their understanding of the biology core ideas and strategically integrate them into their explanatory models via the TBs tool. Some examples of those videos are those developed by Bayer (2016), Giesecke, A., & Schork, N. (2015), and Leyh (2012).

**Implementation.** Twenty-four elementary pre-service teachers (6 groups) socially participated in the three pedagogies and used the associated pedagogical tools. Each group met separately during three face-to-face sessions that lasted between sixty to ninety minutes. During the first session, pre-service teachers started by defining a phenomenon and framing an overarching question, which drives the investigation (a driving question). Then, in the second session, they constructed an explanatory model of the defined phenomenon to answer the driving question. Finally, in the third session, they designed a coherent sequence of intermediate questions and partial models as the stages that might maintain students' engagement throughout the modeling-based investigation. The groups worked without external intervention. The researcher was present with the group during the enactment time and collected the data (video recordings and material representations the group created while video recorded). However, she was not involved in the group's work as the intention was to characterize how the design supported the group's learning.

**Analysis.** The professional vision (Goodwin, 1994) was used to theoretically and analytically examine the groups' discourses using its three discursive practices: highlighting, coding, and material representations (MRs). Through the lens of this framework, it was possible to characterize the social interchange by which pre-service elementary teachers within a group learn to plan MBIs. Learning as PV includes how communities shape, build, and contest decisions to improve their professional scrutiny (Goodwin, 1994).

The analysis of pre-service teachers' discourses through the lenses of PV was carried out in four phases. The *first analytical phase* corresponded to a larger-sized analysis of the video recordings where the groups participated in each pedagogy with the support of the pedagogical tool. Event maps were created to identify key events (Kelly & Chen, 1999). Key events denote the kind of activities initiated, enacted, and bound interactively by the participants with a distinctive focus or purpose (Green & Kelly, 2019). This analysis identified features of their PV for planning MBIs. For example, the instances in which the group defined a biological phenomenon to investigate or used the TBs to interpret that phenomenon. When creating the event maps, research notes were included. These notes allow identifying sub/events or episodes that represented more concerted and coordinated actions of pre-service teachers within a group.

Episodes were established as the units of analysis because the group shaped their discourse through negotiation around particular themes. Initial open codes were created for those episodes in order to distinguish the elements of the professional vision expected from the groups' work (e.g., characterizing changes, characterizing stabilities related to changes, identifying relevant aspects from the video, associating TBs to structures). Appendix B illustrates the event map of one of the groups (four individuals) that participated in the first cycle. This event map corresponds to the 241 minutes the group spent enacting the three

pedagogies while working with the pedagogical tools. The group planned a modeling-based investigation around the biology core idea of interdependent relationships of organisms in ecosystems. They used a phenomenological context related to this idea concerning two organisms (maggot and fungi) building up an environment in a plum.

The *second analytical phase* corresponded to the transcription of the episodes for further analysis. The transcripts included lines of dialogue (i.e., preservice teachers' utterances) and actions (i.e., what they were physically doing) (Kelly & Chen, 1999). The timespans in which the group's discussion was around different themes (e.g., who/how to draw, educational policy, or other personal topics) were not transcribed since these themes do not concern the kind of PV of interest. All the pre-service teachers' names were pseudonymized to ensure that the data collected was used for research purposes and had nothing to do with their final course degree.

In the *third analytical phase*, a small-scale analysis of those transcripts was carried out. The three discursive practices of PV were used to interpret line-by-line pre-service teachers' talk and actions by asking the following: What did they highlight? How did they code, create, or utilize their MRs? For example, *highlighting* were identified utterances that start with: "I think this is important [e.g., the biology core idea].", "What else do we have [e.g., in relation to the model]?", "This [e.g., an aspect of the biology core idea] could be better, right?". *Coding* corresponded to the utterances that, in the course of the talk, capture the participants' interpretation of the recently highlighted aspect: "Well...", "So...", "Because...", "I mean...", or that press to interpretation: replying after a question, like "Do you mean...?", "Are you saying ... right?", "But..." or "Really?" *Material representations* were identified when participants created the explanatory models or used them in the course of the discussion (e.g., by pointing at them, recalling ideas represented on them).

This third analytical phase was central to characterizing pre-service teachers learning as they negotiated their PV for planning MBIs through discourses within the designed learning environment. With this analysis, it was possible to clarify the initial episodes. An episode began when the group engaged in bounded turns of talk and action around one theme and ended when they changed to another. Appendix C illustrates the analysis in the third phase of a sixty-minute section of the total 241 minutes event map in Appendix B. In this section, the group participated in the pedagogy concerning developing an explanatory model via the biology-specific support of TBs uses and content videos while working with the corresponding pedagogical tool. In this case, the discursive practices of highlighting, coding, and MRs allowed an understanding of how the group interpreted the changes involved in the interaction between maggot and fungi with their environment (a plum) as biological transformations.

In the *fourth analytical phase*, new codes were created for the themes that emerged in each episode from the groups' coding. These emergent themes were tracked back to identify patterns and characterize pre-service teachers' learning process considering the focus of each study cycle. Table 3 below shows an example of how the analysis was specified in the four phases. This example corresponded to the first seventeenth minutes when the group developed their explanatory model of the interaction of maggot and fungi with the plum (the detailed analysis can be seen in Appendix C).

Table 3 illustrates how an initial code was assigned to each episode considering the particular TBs themes the group was engaged in (see the first column). Notice that the timespan between the second and third episodes (3:01-7:59 minutes) was not identified as an analysis unit and thus has no codes. One video played for these almost five minutes, and the group did not discuss it. In the second column are the transcripts verbatim in which pre-service teachers' actions were included in parenthesis. One part of the third episode has been provided to

illustrate the small-sized analysis using PV's discursive practices (see the third column). Although the example corresponds to a small piece of transcript (lines 53-61 in Appendix C), it shows how pre-service teachers' learning was characterized as meanings around planning MBIs were negotiated within a group.

First Phase		Second Phase	Third Phase	Four Phase
Episodes	Lines	Discourses (talk and actions)	Analysis through PV discursive practices	Emergent themes
1 [0:00-1:45] Associate TBs with structures	$ \begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \end{array} $	Hallie: Again, a question about the fly. So, the larva [maggot] then develops into a fly. Does the fly stay near the plum and the tree, or is it flying? [Hallie	<ul> <li><u>Highlighting</u> the aspect that the larva develops into a fly as relevant to explain the change in the plum.</li> <li><i>Coding</i> that the fly is</li> </ul>	<i>Integrating</i> the aspect concerning the co- existence of organisms to explain the possible interaction between TB- tree with plums and a TB-fly
2 [1:46-3:00] Characterizing stabilities	8 9 10 11 12	MR.] Anne: I do not know that. Ellen: I did not hear about it either. Anne: Now, you mean	<ul> <li>looking for a near place where the eggs can survive. The fly can also benefit from the plum as a food source. The group explains why maggots "appear" in the plum. It is because a fly was looking for a suitable place for its eggs.</li> <li>Using the MRs as a tool that supports the highlighting and coding</li> </ul>	<i>Contrasting</i> the aspect concerning the constant presence of fungi spores in the air with the plum change.
3 · [8:00-11:47] Identify what each TB does	12 13 14 15 16 17 18 19 20	<ul> <li>12 Anne: Now, you mean</li> <li>13 that if it'll [the fly] lay</li> <li>14 its eggs there again, it</li> <li>15 will remain at its food</li> <li>16 source [the plum]?</li> <li>17 Ellen: Alright, so I do</li> <li>18 not know how far it</li> <li>19 flies, but it will stay</li> <li>20 around, so it can</li> <li>why maggots "appear"</li> <li>in the plum. It is</li> <li>because a fly was</li> <li>looking for a suitable</li> <li>place for its eggs.</li> <li>Using the MRs as a</li> <li>tool that supports the</li> <li>highlighting and coding</li> </ul>		• <i>Integrating</i> the aspect concerning the dependence or organisms from external resources to explain the phenomenon in terms that the TB-fly is causing the plum's biological transformation.
4 [12:00-17:03] Identify transformation s inside the TBs	Ĺ		J	<i>Integrating</i> the aspect concerning the relationship of organisms with external resources to build an environment to explain how TB-fungi and TB- maggot build up an environment inside the TB-plum as their needs are met.

Table 3. Examples of The Four Phases of Analysis

As shown in the third column (Table 3), the group highlighted an aspect of the biology core idea ("*larva/maggot develop into a fly*"), and then, they coded, or negotiated meaning, to this highlighted aspect (the fly looks for a source of food and a suitable place for its eggs to develop). From this group's coding, a theme emerged related to integrating aspects of the biology core idea into the explanatory model (see the last column). Although the complete analysis of the first, second, and fourth episodes is not provided in Table 3, the emergent themes are added to show a pattern identified in the group discourses. In this case, the theme involves integrating biology core idea aspects concerning the interdependent relationships of organisms and their environments into models/explanations of a defined phenomenon via TBs. The four-phased analysis allowed to characterize the first design and implementation's theoretical and practical contributions. It also serves as the foundation to identify opportunities to re-design and improve the second cycle.

*Theoretical contribution.* The first cycle's findings illustrate pre-service elementary teachers engaged in epistemic negotiation when developing mechanistic explanatory models through TBs. At the same time, they engaged in pedagogical negotiation when de-constructing these models. The central theoretical contribution of this cycle was related to the use of discipline-specific epistemic tools in science teacher education when articulating pedagogies and pedagogical tools. In this case, the biology-specific epistemic tool of TBs supported preservice teachers' negotiation of epistemic meanings to build understandings that integrate a variety of aspects of biology core ideas into developing mechanistic explanatory models. In addition, this TBs tool supported their negotiation of pedagogical meanings, so the developed models serve not only to explain a phenomenon but also to structure the modeling-based investigation, for example, by framing driving and intermediate questions.

*Practical contribution*. Groups of pre-service teachers enacting each of the pedagogies and using the associated pedagogical tools during independent sessions were beneficial for their learning process. Pre-service teachers did not participate in each pedagogy as rote activities but engaged in discourses for particular epistemic or pedagogical purposes. Since the beginning, groups of pre-service teachers assumed the responsibility of their practice going further than the intended support. This responsibility is crucial to pre-service teachers' learning as it helps them hold each other accountable for their learning based on the meanings they socially negotiated and the purposes they defined by themselves. This is important in their PV for planning MBIs because they learn to approach this kind of teaching as a social activity in the classroom and peer collaboration.

*Opportunities to improve.* When analyzing pre-service teachers' discourses through the PV lens, it was noticed that there were some elements of their learning to plan MBIs still implicit in their ways of talking and acting. The groups used aspects of biology core ideas for interpreting changes in their phenomenon as biological transformations and integrated them into the mechanistic explanatory model. Although there was an effort to make this integration, they lost track of targeted aspects they planned to address during the modeling-based investigation. For example, the group working on the phenomenon concerning the interaction plum-maggot/fungi referred to the aspect of a plum shriveling. However, they did not characterize "water" as stability and related it to a change in "the amount of water" (at the beginning, there is more water inside the plum). This led them to lose track of how the exchanges of matter, in this case, water between the two organisms and the plum, constitute a relevant goal in their modeling-based investigation. This "loss of track" seemed to be because these elements (e.g., explicitly discussing the relevance of stabilities and changes for the MBIs) could not be visible for pre-service teachers and were not consistent through the pedagogies and pedagogical tools.

In this case, an opportunity to improve arose regarding how teacher educators as designers need to respond to the emergent features within a learning environment. It was necessary to modify the pedagogies and the pedagogical tools by explicitly engaging preservice teachers in distinguishing what they aim to teach throughout the planning practice. Since they start defining a natural phenomenon, pre-service teachers need support identifying what to teach as the epistemic goals. Then, they need support for concreting those epistemic goals when developing mechanistic explanatory models and designing the instructional sequence that eventually helps their students to achieve those goals. Upon this base, contributions and improvement opportunities were considered for the second cycle.

#### **5.3 Second iterative cycle**

The second cycle focused on how pre-service elementary teachers, when negotiating meanings around planning MBIs, comprehend the twofold aim of this practice: epistemic and pedagogical.

**Design.** For the second iterative cycle, the design conjecture was that groups of preservice elementary teachers socially participating in the three re-structured pedagogies and using the refined version of pedagogical tools would engage in discourses where specific elements of planning MBIs are explicitly negotiated. Two main design elements were improved, one regarding the task structure (See yellow box in the conjecture map, Figure 2) and another regarding the resources (See orange box Figure 2). This re-design was carried out considering two main criteria: (a) re-structuring the pedagogies to increase the saliency of the aspects of planning MBIs and (b) simplifying the pedagogical tools towards more productive discourses (i.e., discussions that help make sense of more specific aspects of the practice). These modifications and complements were necessary to improve the support provided to preservice teachers within the designed learning environment. Improvement of task structure. The three pedagogies and corresponding pedagogical tools (See Table 2) were refined to support pre-service teachers by making their ideas explicit and consistently associating the practice elements. This refinement was made by attending to the conceptual aspect of small-scale negotiations (Thompson et al., 2015) or "micro-negotiations." It was expected that re-organizing tasks around micro-negotiations ensures pre-service teachers understand how it is that their participation in planning MBIs is essential for achieving the purposes. Through micro-negotiations, pre-service teachers engage in each task comprehending the ultimate purposes of that engagement for their role as students and future teachers. Table 4 provides some examples of the modifications made in the pedagogical tools. Appendix D contains a complete version of the three pedagogical tools designed, implemented, and studied during this second iterative cycle. These tools are the refined version of the example in Appendix A. Appendix D also includes what was expected from the group's work according to the theoretical and practical implications of the first iterative cycle.

Pedagogy	First c	ycle	Second cycle		
	Decomposition of practice	Representation of practice	Decomposition of practice	Representation of practice	
1	Identify and characterize changes and stabilities in a phenomenon.	Use the general visual representation of TBs to identify changes and stabilities.	<ul> <li>Identify and characterize changes considering the following prompts:</li> <li>(a) Initial and final situations</li> <li>(b) Extreme conditions</li> <li>(c) Different levels (observable and unobservable)</li> <li>(d) Different speed rates</li> <li>(e) Different times, places, or at a certain distance.</li> </ul>	Use a representation based on TBs of each prompt (a) to (e).	
2	Analyze online biology videos (every two minutes) to identify the	Use the general and visual representation of TBs to improve (every	Analyze the entire video to characterize in the biological structures what changes or remains stable, following	Use the general visual representation of TBs. Focus on the dimensions before and after a biological	

**Table 4.** Examples of the Modifications Made in the Pedagogies and Associated Pedagogical

 Tools for the Second Iterative Cycle

	usefulness of biology core ideas for interpreting the phenomenon.	two minutes) the identified changes and stabilities.	pro din (a) (b) (c)	mpts for each epistemic nension: Matter, Energy Information.	transformation (three arrows going in and out of the TBs).
3	Develop a sequence of intermediate questions that target the phenomenon's specific features (changes- stabilities) or the biology core idea.	Use an abstract representation of an explanatory model based on TBs	(a) (b)	Develop a sequence of intermediate questions. Identify the aspects of the biology core idea targeted with each intermediate question. These aspects help interpret the specific features of the phenomenon to construct partial models/explanations.	Use an abstract representation of an explanatory model based on TBs, emphasizing that one of the ways to construct partial models/explanations is by targeting specific aspects of the biology core ideas.

The most significant modifications shown in Table 4 were regarding decompositions and representations of practice. This was consistent with the conceptual element of micronegotiations. The approximations of practice in each case were kept as it was intended that pre-service teachers participate in the practice of planning MBIs authentically. The activities of these approximations of practice were decomposed into more minor elements, so the restructured decompositions were proposed to enable pre-service teachers to see and enact the elements that were still implicit to them. Representations of practice were also modified to clarify the use of the epistemic tool of TBs and therefore support the groups' negotiation of meanings. This re-structuration of the decompositions and representations does not mean that the practice became more complex for pre-service teachers or that the pedagogical tools had additional sections. On the contrary, the refined versions of the pedagogical tools constitute a simplified form of the initially implemented (See differences in Appendix A and D).

The pedagogical tools implemented during the second cycle do not contain the section "before continuing" because it seemed that having these two sections across the tool did not contribute to clarifying the practice. Instead, the group lost track of relevant elements, such as
identifying what they aim to teach about the biology core ideas and the modeling practice. Therefore, for the second cycle, open-ended questions and statements to discuss were proposed in the same task section, so it was more precise for the group what they needed to consider for enacting the tasks and understanding what they were doing in each case.

Improvement of resources. These pedagogical tools were also articulated as Multimedia-Tools in an online learning environment designed using the learning management system ILIAS<sup>®</sup>. Multimedia-Tools aimed to enhance the groups' engagement in each proposed task and prompts through forums, blogs, data collection tables, and Etherpads as web-based resources. Blogs have been used in science teacher education to expand in-class discussions and are supportive, especially in cases where pre-service teachers are good at writing rather than talking (Cakir, 2013). Researchers have used forums, particularly the Knowledge Forum educational software, to support knowledge-building communities (Allaire, 2015) and as an effective venue for peer feedback (Foo, 2021). Etherpads have enabled preservice teachers to simultaneously write their ideas and discuss via task before concreting shared understanding (Rehak et al., 2016). This resource also allows researchers to identify individual contributions (shown in different colors) and follow the collaborative process via a time slider (Pymm & Hay, 2014). Figure 4 is a general illustration of the refined version of one pedagogical tool articulated and implemented through the ILIAS® platform during the second cycle. This tool corresponds to the pedagogy to support pre-service teachers in developing an explanatory model via TBs and the content videos.

**Figure 4.** *Pedagogical Tool Articulated and Implemented Through the Learning Management System ILIAS*<sup>®</sup>.



As shown in Figure 4, the primary web-based resources used were blogs, forums, and Etherpads. In this example, the blog aimed to allow the exchange of initial ideas about the provided content videos by commenting on what can or cannot help interpret the changes in their phenomenon as biological transformations. These initial ideas were expected to be used further in the forum. The forum aimed to facilitate discussions and collaboration in developing a mechanistic explanatory model via TBs. Finally, the Etherpad aimed to support the coconstruction of a written explanation that manifests the causal chains (the different relationships of components), including aspects of the content that explain the phenomenon. Appendix E shows an example of the data collected and the first analysis phase (event map) from pre-service teachers' participation in the three pedagogies for planning MBIs while participating through the web-based sources in each Multimedia-Tool. The example corresponds to a group (five individuals) planning their modeling-based investigation around the biology core idea of ecosystems dynamics, functioning, and resilience. They worked their planning in the context of a phenomenon related to the influence of external conditions on mosquitos biting people.

Implementation. Seventy-two elementary pre-service teachers (15 groups) socially enacted the three re-designed pedagogies and used the associated pedagogical tools. Three groups (fourteen individuals) met separately during three face-to-face sessions that lasted between sixty to ninety minutes. During each session, these three groups participate in one of the pedagogies, starting with the definition of the phenomenon, then the development of the mechanistic explanatory model, and finally, the design of the instructional sequence. The remaining twelve groups (fifty-eight individuals) were encouraged to work in the re-designed as Multimedia-Tools in a blended online environment on ILIAS® platform. The Multimedia-Tools were available to pre-service teachers from the beginning of the course. The groups were able to participate in the activities independently and according to their time and space possibilities. Each group has its own space within the platform to ensure pre-service teachers express their ideas more confidently and concentrate on the biology core idea they address in their planning. This avoids comparison among groups and allows researchers to follow each group's participation and give them more specific feedback and guidance.

**Analysis.** The professional vision framework and the four analytical phases of the first cycle remain during the second cycle. There was an improvement in the data analysis, especially during the third (analysis through PV discursive practices) and fourth (identification of emergent themes) phases. In this case, computer-based tools were explored to carefully identify the interaction between pre-service teachers and the contextual features, including the physical and social resources. This was consistent with DBR's purpose of enriching

researchers' understanding of the relationship between mediating processes, the design, and the outcomes (Design-Based Research Collective, 2003).

The NVivo 11 Pro computer software produced by QSR International ® was used as a computed-based tool to facilitate the data analysis, especially the small-grained size of the face-to-face groups, through the lens of PV's discursive practices. The different data sources, namely video recordings and material representations, were imported into NVivo. The software allowed coding these sources in various ways depending on the research progress and the variations made as the second study's focus became more precise.

Figure 5 below shows an example of the discourse analysis through NVivo of one of the groups (four individuals) in the face-to-face setting of the second cycle. This analysis corresponds to a section of seventeen minutes (out of fifty-five minutes) that they spent enacting the pedagogy and used the pedagogical tool that supported them in developing an explanatory model of the phenomenon (second pedagogy). The group planned a modeling-based investigation around the biology core idea of information processing by organisms and defined a phenomenon regarding how children experience excitement differently when they need to talk in front of the class.

As shown in Figure 5, the NVivo software enabled synchronizing the video recording with the transcript. This was critical to the dissertation work because of the interest in interpreting pre-service teachers' discourses, considering both their ways of talking and acting. During this seventeen-minute section, the group engaged in a key event orienting their discourses for integrating aspects of the biology core idea into the model. From the five subevents or episodes that constitute this key event, it was possible to start identifying some patterns, such as the group's emphasis on characterizing TBs-structures and functions (episodes 1 and 3).



#### Figure 5. Example of the Discourses Analysis Through NVivo

The NVivo software was also relevant to identifying themes and patterns using coding queries and visualizations. For example, Figure 6 is a connection map that visualizes a group query that looked for the codes of the groups' discourses during the fifty-five minutes that their participation in the second pedagogy lasted. This visualization was useful to start making some claims about the group's learning process. For example, although the group developed the explanatory model of their phenomenon by evaluating and constructing their model with epistemic (E) and pedagogical purposes (P), they prioritized epistemic purposes. As shown in Figure 6, there are more connections to constructing and evaluating the model (E) than to (P).

#### Figure 6. Connection Map that Visualizes a Group Query in NVivo



*Theoretical contribution.* Given that it was an in-depth analysis of pre-service teachers' discourses (via NVivo), a central theoretical contribution of this study was related to the use of PV as the theoretical and analytical framework. The back-and-forth analysis of pre-service teachers' discourses to characterize how they learned within the context and the opportunities provided to support them, also allowed an in-depth comprehension of the PV framework. The PV was conceptualized from a sociocultural perspective grounded in Goodwin's (1994) original notion and emphasized four central points. PV is not a lens to see teaching that novices can acquire but is negotiated in a community. PV emerges and is analyzed in pre-service teachers' discourses. PV's development is characterized by how pre-service teachers highlighted, coded, created, and used material representation within a group. In PV, these material representations can not be ignored as they manifest pre-service teachers' openness and flexibility of understanding and decisions regarding the teaching profession.

*Practical contribution.* Groups of pre-service teachers participating in specific components of planning MBIs mediated by web-based resources such as forums, blogs, data collection tables, and Etherpads were relevant for increasing their engagement within a group.

A combination of structures and resources (web, content, and epistemic-based) was critical to support pre-service teachers' practice in online learning environments. Such combinations serve as direct mediators of their negotiation of meanings around planning MBIs.

#### 6. Research Products

Three main products consolidated in the following sections have resulted from the dissertation work. The first corresponds to an empirical manuscript (manuscript I) derived from the first iterative design, implementation, and analysis cycle (Téllez-Acosta et al., 2022a). This manuscript I approaches how groups of pre-service elementary teachers develop PV for planning MBIs by engaging in epistemic and pedagogical negotiations. The central contribution to science teacher education that emerged from this first study was that the biology-specific epistemic tool of TBs embedded in the pedagogies and associated pedagogical tools fosters pre-service teachers' flexibility in dealing with disciplinary core ideas and scientific modeling (i.e., epistemic negotiation). This TB tool also opens possibilities for structuring the modeling-based investigation (i.e., pedagogical negotiation).

The second product corresponds to a chapter derived from the second iterative cycle (manuscript II; Tellez-Acosta et al., 2021). In this case, the re-designed pedagogies and pedagogical tools were articulated as a set of epistemic, disciplinary, practical (pedagogical), and interactive Multimedia-tools. The main contribution of this study to the science teacher education field is that a goal-oriented combination of web-based resources enhanced preservice teachers' discussion and engagement in each of the proposed tasks. This study suggests that the epistemic components (i.e., a biology-specific epistemic tool) and disciplinary (i.e., online content videos) supported pre-service teachers by integrating aspects of biology core ideas into explanatory models while socially participating in scientific modeling. In addition, the study suggests that the practical (i.e., focus on specific aspects of planning modeling-based investigations) and interactive (i.e., web-based resources such as forums, blogs, data collection tables, and Etherpads) components increased within-group engagement.

The third product corresponds to a theoretical manuscript about professional vision as a theoretical and analytical framework (manuscript III; Téllez-Acosta, McDonald & Acher, 2022a). This manuscript III was motivated by four tensions found in conceptualizing this professional vision framework and its relation to cognitive and sociocultural learning perspectives: (a) the nature of pedagogies, (b) the kind of evidence sources, (c) the analytical methods, and (d) the role of material representations. These four tensions were approached by discussing examples of the work with groups of pre-service elementary teachers during the second iterative cycle. This manuscript contributes to recognizing the value of a sociocultural perspective of learning to expand teacher education efforts. Mainly, the emphasis is on the design of learning environments and the study of learning to consider the inseparable relationship between pre-service teachers building professional knowledge (shared understandings) and the social and physical resources within those learning environments.

# 6.1 Manuscript I. Empirical paper

Téllez-Acosta, M.E., Acher, A. & McDonald, S. (2022a). *Pre-service Elementary Teachers' Developing Professional Vision for Planning Modeling-Based Investigations*. Manuscript under review, Submitted on February 21st 2022

# **Pre-service Elementary Teachers' Developing Professional Vision for Planning Modelling-Based Investigations**

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The authors report there are no competing interests to declare.

# Pre-service Elementary Teachers' Developing Professional Vision for Planning Modelling-Based Investigations

Pre-service elementary teachers developing professional vision for planning modellingbased investigations (MBIs) prepares them to guide students to explain phenomena while engaged in the practices of science and learning disciplinary ideas. While research has less focused on how pre-service teachers build shared understandings, examining the development of professional vision as the negotiation of meanings in authentic discourserich learning contexts provides insights about their learning as a process. This study aims to characterize how the negotiation around planning MBIs of a group of pre-service elementary teachers unfolds in a professional learning environment. We use the professional vision (Goodwin, 1994) as a theoretical and analytical framework to examine their highlighting and coding of relevant aspects of disciplinary core ideas, modelling, and structuring a modelling-based investigation as well as the creation and use of material representations to build shared understandings. The findings illustrate two themes of pre-service teachers' negotiation around planning MBIs: a) epistemic negotiation when developing mechanistic explanatory models, and b) pedagogical negotiation for structuring a modelling-based investigation through the de-construction of those explanatory models. We discuss how a discipline-specific epistemic tool was used to support flexibility in epistemic negotiation and opens possibilities for the negotiation of pedagogical meanings.

Keywords: pre-service elementary teachers; planning modelling-based investigations; disciplinary core ideas; scientific modelling; professional vision

#### 6.2 Manuscript II. Empirical book chapter

Tellez-Acosta, M.E., Acher, A., & Kusitzky, L. (2021). Unterstüzzung von Grundschullehramtsstudierenden bei der Integration von naturwissenschaftlichen Fachwissen aus Online-Videos in die Modellierungsprozesse durch "Multimedia-Tools." In T. Schubert, M. Gerth, & W. Zimmerman (Eds.), *Multimediales Lehren und Lernen an der Martin-Luther-Universität Halle-Wittenberg. Befunde und Ansätze aus dem Forschungsförderprogramm des Zentrums für multimediales Lehren und Lernen (LLZ)* (pp. 25–40). Halle (Saale). https://doi.org/http://dx.doi.org/10.25673/38465



#### 6.3 Manuscript III. Theoretical paper

Téllez-Acosta, M.E., McDonald, S. & Acher, A. (2022a). Sociocultural and cognitive ways of conceptualizing professional vision to support and study novice teachers' learning. Manuscript under review. Submitted on January 25th 2022

#### Sociocultural and Cognitive Ways of Conceptualizing Professional Vision to Support

#### and Study Novice Teachers' Learning

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We have no known conflict of interest to disclose.

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#### Abstract

With the increased focus on novice teachers' learning through practice, there is also a need for us as teacher educators to find suitable frameworks for interpreting this learning to better support it. The professional vision framework has been used for this interpretative purpose and in a variety of contexts. We have found that there are still differences in conceptualizing this framework and its relation to cognitive and sociocultural learning perspectives. This paper aims to approach these differences as valuable tensions we can work on to expand teacher education efforts in designing learning environments and studying learning within those environments. Four central tensions are regarding: (a) the nature of teacher education pedagogies to support novices in developing their PV, (b) the kind of evidence sources, (c) the analytical methods used to study novices' PV development, and (d) the role of material representations in novices' PV development. We discuss some examples of our work with science elementary novice teachers when learning to plan modeling-based investigations to approach these tensions. In this way, we emphasize that conceptualizing PV as a collective process in authentic practice rather than knowledge acquired and then transferred to practice provides teacher educators with meaningful information about novices' learning. Upon this base, we provide new insights that might add value to the design and study of learning environments that effectively sustain novices' professional learning through practice.

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#### 9. Appendixes

# 9.1 Appendix A. First Iterative Cycle's Pedagogical Tools.

# 9.1.1 Pedagogical tool 1

# Unterstützendes Tool 1: "Veränderungen im Phänomen wahrnehmen und dabei Aspekte von Stabilität entdecken"

Ziel: Entwicklung des Phänomenologischen Kontextes anhand der Erarbeitung von Veränderungen und Beständigkeiten (Change- und Stability-Aspekten).

Bearbeitet die folgenden 5 Aufgaben zusammen in eurer Gruppe. Achtet besonders auf die Hinweise zwischen den Erarbeitungsschritten, welche mit 'Bevor es weitergeht...' gekennzeichnet sind.

Teil I: Identifizierung der Veränderungen in einem Phänomen Was verändert sich im Phänomen?	
1.	Was verändert sich im Phänomen? Beginnt eine kurze Geschichte mit mehreren handelnden Figuren zu schreiben. Beim Entdecken und Untersuchen der Veränderungen des natürlichen Phänomens, sollen die verschiedenen Sichtweisen der Figuren deutlich werden. Wie denken sie über die Veränderungen, wenn sie das natürliche Phänomen wahrnehmen oder sich vorstellen?
Bevor e	<b>s weitergeht</b> Die Figuren eurer Kurzgeschichte sollten verschiedene Sichtweisen entwickeln, während sie die Voränderungen gemeingen und individuell zu verschiedenen Zeitnumkten und en verschiedenen
Co-con.	Veranderungen gemeinsam und individuell zu verschiedenen Zeitpunkten und an verschiedenen Orten betrachten. Diskutiert, auf welche Weise ihr das in eurer Geschichte ermöglichen könnt. structing the idea of change as a process through time and space dimensions.
b) Co-con.	Eure Figuren sollten dabei verschieden intensiv auf die Veränderungen eingehen, d.h. manche bringen große Veränderungen zum Tragen, andere kleinere. Die Veränderungen sollen auch in Hinblick auf extreme Bedingungen betrachtet werden. Diskutiert, wie ihr die Gespräche und Interaktionen über die verschiedenen Sichtweisen eurer Figuren in eurer Geschichte darstellt. structing the idea of change through magnitude dimension.
c) Co-con.	Die Figuren eurer Geschichte sollten sowohl die Ausgangssituation im Phänomen, aus der die Veränderungen resultieren als auch die Ergebnisse der Veränderung betrachten. Diskutiert über die Möglichkeiten, wie die Figuren diese vorgestellten/ wahrgenommenen Ausgangssituationen untereinander austauschen. structing the idea of change through material transformations.


*jemandem in eurer Gruppe, der es schwierig findet, stabile Aspekte zu finden. Hangelt euch entlang dieser Fragen:* 

*Characterizing changes based on the uncertainness emerging from the co-construction of change-stability antinomies.* 

- Wie würden sich die Produkte der Veränderung ändern, wenn Aspekte, die ihr als veränderlich identifiziert habt, sich doch nicht ändern?
- Wie würden sich die Ergebnisse der Veränderung ändern, wenn sich stabile Aspekte auch verändern würden?
- Dreht das Ganze einmal um: Stell dir eine Veränderung vor, die plötzlich stabile Aspekte aufweist, und einen stabilen Aspekt, der sich nun verändert. Wie würde das Ergebnis deiner ursprünglichen Veränderung aussehen? Gibt es etwas, bei dem du dir noch unschlüssig bist, ob es sich verändert oder nicht?
- **4.** Vollendet die Geschichte, die ihr in Punkt 1 begonnen habt. Dieses Mal überarbeitet den phänomenologischen Kontext (PK) und verbessert die Geschichte mit den neu gewonnenen Informationen aus den TBs bezogen auf Aspekte von Stability und Change.

#### Bevor es weitergeht...

- a) Ihr habt jetzt bessere Darstellungen für die Veränderungen gefunden, die sich in dem natürlichen Phänomen vollziehen. Nehmt 1-2 Veränderungen und lasst die Personen eurer Geschichte Widersprüche austauschen:
  - Wie würden sie die Aspekte der Veränderungen, die ihr herauskristallisiert habt, nutzen, um ihre ursprünglichen Sichtweisen zu rechtfertigen?
  - Welche Veränderungen oder Aspekte der Veränderungen würden besser für solche Widersprüche passen? Diskutiert in der Gruppe und begründet eure Meinungen!
  - **5.** Formuliert 3-4 mögliche Leitfragen (LF). Versucht davon ausgehend die Frage, die am besten Aspekte von Stability und Change des Phänomens aufgreift, zu finden.

### 9.1.2 Pedagogical tool 2

## Unterstützendes Tool 2: "Verstehen der Kernideen durch die Nutzung von Transformations-Boxen"

**Ziel:** Untersucht die sich verändernden und stabilen Aspekte, die ihr im Phänomen entdeckt habt, um biologische Transformationen beruhend auf eurem Verständnis von der Kernidee aus dem Video durch Transformation Boxen zu bestimmen und zu organisieren.

Bearbeitet die folgenden 3 Aufgaben gemeinsam in eurer Gruppe. Achtet besonders auf die Hinweise zwischen den Erarbeitungsschritten, welche mit **'Bevor es weitergeht...'** gekennzeichnet sind.

#### Teil I: Aufgaben zum Videoclip

1. Als eine Planungspraxis müsst ihr aussagekräftige Modelle konstruieren, mit welchen ihr euren SuS helft das Naturphänomen zu erklären. Transformationsboxen dienen dafür als Hilfsmittel. Um diese Boxen weiter zu verbessern, müsst ihr Entscheidungen basierend auf eurem Verständnis der veränderlichen und stabilen Aspekte des Phänomens sowie der Bedeutung der Kernidee aus dem Video treffen.

*De-constructing scientific content knowledge from videos through its relation with the natural phenomenon –changes and stabilities-*

- a. Seht euch das Video in 2-minütigen Abschnitten an. Übertragt eure Darstellungen der Veränderungen/Stabilitäten (Boxen) von TOOL 1 in die erste Spalte der Tabelle unten. Versucht dabei die Darstellungen so gut wie möglich den Videoabschnitten zuzuordnen.
- b. Beginnt dann die Darstellungen anhand der Schritte in den weiteren Spalten daneben zu überarbeiten. (*Für diese Aufgabe muss nicht notwendigerweise jeder Abschnitt produktiv sein.*)

Im Verlauf des Videos werden Veränderungen und Stabilitäten detaillierter, sodass ihr in der Überarbeitung der Transformationsboxen überlegt vorgehen solltet. Eure Boxen sollen während ihr das Video seht, ständig verfeinert werden. Achtet also darauf, dass ihr immer über die Details diskutiert, die ihr besonders relevant für die Verbesserung eurer Transformationsboxen haltet. Die Begriffe in den rechten Spalten sollten euch helfen diese Relevanz zu verstehen. **Fügt mehr Boxen hinzu, wenn ihr sie benötigt.** 

#### Bevor es weitergeht...

*a)* Verfeinert/detailliert eure Beschreibung der Anfangs- und der Endsituation der Veränderung. (beide Seiten der Transformation)

*Identifying the changes associated with the phenomenon, conditions (e.g., temperature, humidity), features (e.g., color), or factors (e.g., distance)* 

- Was löst die Veränderung aus? Ist es ein Aspekt der Materie-Energie und/oder Signalisierung? Wenn ihr euch nicht sicher seid, sucht euch einen der beiden Aspekte vor Eintritt der Veränderung aus und steigert die Menge oder Verfügbarkeit: tritt die Veränderung jetzt ein?
- Was sind die Konsequenzen der Veränderung? Hat dieser Einfluss auf Materie, Signalisierung und/oder Energie?
- > Vergleicht jetzt die Anfangs- und Endzustände der Veränderung.

b) Die organischen Strukturen: Was sind die Teile eurer Organismen, die für die Erklärung der Veränderungen eine Rolle spielen? Diskutiert die Möglichkeit eine Box in kleine Boxen zu teilen. Erkennt die Details der Boxen... mit mehr Boxen. Nutzt die vorgegebenen Darstellungen zu eurer Orientierung.

Associating TBs with structures, organisms, or components of them.

Ihr könntet Veränderungen bemerken, die ihr nicht berücksichtigt habt und welche auf verschiedenen Ebenen vorgehen. Jetzt, nach dem Sehen des Videos, habt ihr die Möglichkeit zu entscheiden, welche Veränderungen ihr auf den verschiedenen Ebenen einbeziehen wollt.

Fokus Abschnitt/Ze iten	<b>Phänomenologische</b> <b>Veränderungen/ Stabilitäten</b> (die Boxen, die ihr am Ende von Tool 1 festgehalten habt)	Überarbeiten/Verfeinern/D Veränderungen/Stabili (die Be Verfeinert/detailliert eure Veränderungen/ <b>Stabilitäten</b> bezüglich der Anfangs- und Endprodukte der Veränderung.	etaillieren eurer Darstellungen der Aspekte der täten mit Boxen unter Einbezug des Videos edeutung der Transformationen verbessern) Unterschiedet sichtbare von den vielen unsichtbaren Transformationen. Identifiziert die organischen Strukturen für die bestehenden oder die neu Boxen.
0 - 2 min	Change + stability # 1 (Veränderung + Aspekte, die nicht verändern) Change + stability # 2 (Veränderung + Aspekte, die nicht verändern)	Verbesserte Version der Stabilities + Changes # 1	Image: Constraint of the second se
2 - 4 min			
4 - 6 min			



3. Ihr seid zu einem komplexen Modell gekommen (Darstellung + schriftliche Erklärung). Trotzdem könntet ihr einige entscheidende Aspekte vergessen haben, welche Einfluss auf das, was ihr erklären wollt, haben.

Seht das Video erneut und beschreibt genau die Bereiche in eurem Modell, welche noch nicht deutlich sind. Dies hilft euch sowohl die Darstellung als auch die Erklärung (geschriebene Sätze) zu überarbeiten.

Bevor es weitergeht...

- a) Nennt das Video Dinge, die euch helfen eure EIGENE Darstellung zu verbessern?
- b) Seid diesmal besonders aufmerksam und konzentriert euch auf: den Austausch zwischen den Boxen (Organismus-Box und Umgebungs-Box oder innere Boxen im Organismus) - die Veränderungen/Stabilitäten (Transformationen durch den Fluss von Materie, Energie und Signalisierung innerhalb und außerhalb der Boxen), - die sichtbaren und unsichtbaren Aspekte. Identifiziert, was in diesen Strukturen fließt und die funktionalen Verbindungen aufrechterhält.
- *c)* Überarbeitet die chronologische Organisation dieses Flusses. (Wie "funktionieren" die Transformationsboxen über einen Zeitraum.)

## 9.1.3 Pedagogical tool 3

## Unterstützendes Tool 3: "Hilfe zum Konstruieren der Tabelle [modellbasierte Untersuchung]"

Ziel: Nutzen der bereits erstellten, fundierten Modelle zur Vollendung der Tabelle

Bearbeitet die folgenden 4 Aufgaben zusammen in der Gruppe. Achtet besonders auf die Übergänge/Zusammenfassungsaufgaben 'Bevor es weitergeht...'



#### Bevor es weitergeht...

a) Identifiziert nochmals die Haupt-Veränderungen des Phänomens, welche ihr im Final-Modell/in der Final-Erklärung festgehalten habt. Wären diese Veränderungen 'zerlegt' besser erklärbar? Geben euch die Boxen selbst, die Verbindungen/Austausche zwischen den Boxen, Edukte und Produkte bzw. der Fluss zwischen den Boxen einen Anhaltspunkt darüber, wie man das Finalmodell zerlegen könnte, sodass eine logische Verknüpfung der Teilmodelle wieder zu einem Final-Modell führen?

De- constructing the "big" model-explanation based on the aspects of the TBs uses, focus on: a) the dimensions of the change: matter, information, energy, b) connection or exchanges among the boxes (flow), c) connection or exchanges of the boxes with the environment, d) structure and/or function

*b)* Das gesehene Video war symbolisch für eure Kernidee (KI). Könnt ihr dabei Wege sehen, wie die Modelle zerlegt werden können um verschiedene Aspekte der KI offen zu legen?

*De-constructing the "big" model/explanation attending to the aspects of the biology core ideas. What is important of the biology core ideas for the purpose of reaching clear steps, partial model/explanations* 

#### Teil II: Teilmodelle und Teilfragen

- 2. Ihr habt nun Teil-Modelle mit verschiedenen Aspekten von Veränderungen im Phänomen, sowie Aspekte eurer Kernidee(n) (KIs) gefunden. Zusammengefasst könnt ihr nun die Leitfrage (LF) beantworten.
  - Entwickelt kleinere Fragen als die LF, mit denen ihr eure modellbasierte Untersuchung organisiert. Jede dieser Fragen soll mit euren Teil-Modellen/-Erklärungen beantwortet werden können.

Teil-Modell	Teil-Frage
1	
2	
3	
4	

Bevor es weitergeht...

*a)* Teil-Fragen können speziell nur einen Aspekt ansprechen um damit ein Teil-Modell erklären zu können. Welcher Aspekt wäre das? Würden alle Aspekte gemeinsam das Final-Modell/die Final-Erklärung 'beantworten'?

Co-developing partial questions and problems about the new articulation of the changes or the aspects of these that can be answered /modeled/explained

b) Alle Teil-Fragen zusammen müssen als eine Art logisch zusammenhängende Sequenz die LF beantworten. Sind eure Teil-Fragen dafür passend?

#### Teil III: Alternativen mit Hilfe von Teil-Modellen finden

3. Ihr verlasst euch nun auf: Final-, Teil-Modelle/Erklärungen, sowie auf Leitfrage und Teil-Fragen. Vor allem eure Teil-Modelle repräsentieren <u>eine Art um einen Aspekt des Phänomens zu erklären</u>.

- Wählt <u>eins</u> dieser Teil-Modelle und stellt euch vor, wie ein alternatives Modell, welches auf einem anderen Aspekt des Phänomens beruht und eine differente Sichtweise dessen aufzeigt. Achtet dabei auch auf die differente Organisation der TBs.

#### Bevor es weitergeht...

a) Vergleicht eure ersten Teil-Modelle und eure Alternative. Basieren die Alternativen auf der unterschiedlichen Organisation der TBs, den Verbindungen/Austausche zwischen den Boxen, Edukte und Produkte der Boxen oder dem allgemeinen Fluss unter den Boxen? Würde dies zu einem veränderten/differenten Verständnisses bezüglich der Aspekte der KI beitragen?

Evaluating models based on the uncertainties emerging from the modeling process.

#### Teil IV: Phänomenologischer Kontext

- 4. Versucht jetzt euren Phänomenologischen Kontext (PK) basierend auf den Teil-Modellen/Erklärungen und der Leitfrage/Teil-Fragen zu überarbeiten. Passt euer PK dennoch?
  - Geht nochmal auf eure Erstfassung der Kurzgeschichte über euer Naturphänomen ein. Überarbeitet sie final für eure Tabelle ZÜ I.

#### Bevor es weitergeht...

- *a)* Überprüft, ob die Veränderungen/Beständigkeiten, die ihr in eurer Kurzgeschichte zum Tragen gebracht habt, auch in den Teil-Modellen/im Final-Modell erscheinen. Wenn nicht, bringt sie ein.
- *b)* Lest, was eure Figuren der kurzen Geschichte (PK) sagen. Drücken sie Eventualitäten neuer Veränderungen/ Beständigkeiten aus, die ihr in die Geschichte eingebracht habt?

Video	Time Span	Key events	Sub/events	Research Notes
Clip			(Episodes)	
1.1	0:40-9:30	Defining phenomenon	Characterizing the changes	They discuss the ideas for the phenomenological context: a) corn plant and b) plum. Both are related to the biology core idea concerning the relationship between organisms and their environments. One of the aspects on which they based their decisions on which can be more related to situations close to children's contexts and the experiments they can make (materiality of the phenomenon- projecting for the WiSe). They also think about the dimensions of the change associated with these two situations.
				Compared with the group of information processing and adaptation, this group has considered more features of the change at the beginning: times, places and conditions, dimensions
				They start making the "first representations" of the two ideas they have for the phenomenon. In doing so, they consider the TBs and their aspects in each model.
9:31-14:29	-	Constructing initial representations of changes (option 1)	They start creating a model of the corn phenomenon. <i>T</i> he corn plant has one organism (one box).	
			changes (option 1)	I did not collect this model since the group decided the option 2 for their phenomenological context.
	14:30-17:14	-	Constructing initial representations of changes (option 2)	They start creating a model of the plum phenomenon (Figure 1 after the table). The plum has two organisms, the fungus and an animal (2 boxes). They are also considering the dimensions of the change. i.e., how the animal knows that it can come to the plant (they refer to some "fragrances").
1.2	0:00- 2:06	-		They continue with the model of the plum phenomenon. Talk about the conditions and the surroundings of the fruit (the tree). They recognize they need more information about what exactly is happening.
	2:10-4:45		No code	Reading the tool. Choose the class. Organizational. How many students, general aspects of the context.

# 9.2 Appendix B. Example of an event map

	4:46-10:00	Defining phenomenon	Characterizing stabilities related to changes	They identify some differences between a healthy and an unhealthy plum to start identifying the initial and final conditions of the change.
				Describe the changes.
				Unlike the other 2 groups, they made 2 different representations to have an initial idea of how the boxes could look and show the others how they think the change is happening in each situation. Then, based on this first approximation, they start working in the phenomenological context. I think this could be more related to the understanding we are trying to describe in the professional vision because they are using the material representations beforehand to work on the phenomenon.
	10:01- 17:14		No code	Writing. Organizational. Characters speech. What characters can say using appropriate language.
1.3	0:00- 2:00	_		Continue writing
	2:01-4:15	Defining phenomenon	Characterizing changes	Find some reasons for the presence of the organisms in the plum. For example, flies need to cover the "larva- grub-" needs. <i>Include some aspects of the</i> <i>explanation in the context.</i>
	4:16-9:00		No code	Writing.
	9:01- 14:49	Defining phenomenon	Characterizing changes and stabilities	Emerges a question about the limits of the phenomenological context. They know they have just to present a "problem" but are unsure if they have to give some insights for their explanation. Identify the aspects of stability and change. Came back to the phenomenological context they already have and revise these aspects.
	14:50-17:14	Formulating a driving question (DQ)	Constructing DQ	They start exchanging some possibilities for the DQ
1.4	0:00- 1:45	_	Evaluating DQ considering changes and stabilities	Continue with the construction of the possible DQ. Compare two plums in order to identify the stability and change aspects.
	1:46- 2:30		No code	Reading the tool

	2:31- 17:14	Defining the phenomenon	Representing changes as TBs	They are working on the second task of the tool: "Represent the changes of your story using Transformation Boxes."
				It is important to recheck it because it could be confusing.
			Identifying the change dimensions	They start representing individual changes as TBs (Figure 2). They discuss: Which are the boxes and how many boxes? What comes in and what comes out? What inform the fly to come to the fruit?
				The relationship they are trying to make between the boxes is attending to the <b>time</b> having what is happening to the plum in the center. They are problematizing the change base on this variable. They are also considering the stability and change aspects. i.e., is the fungus there when the fly is informed to come?
1.5	0:00- 6:15		-	They continue the discussion.
				2:00 dimension energy. From the sun. <i>What kind of energy?</i>
				It could be the energy that is taken by the worm, maggot, and fungus.
				They discuss if the maggot and fly are one box or two.
	6:16-7:20		No code	No discussion, only drawing.
	7:21- 15:40	Defining the phenomenon	Representing stabilities	They identify and represent stability aspects regarding the identified changes—for example, water and the amount of water (Figure 3).
				While they read the tasks and support (section before continuing), they discuss about those ideas.
	15:41- 17:14	_	Characterizing changes and stabilities	They improve the phenomenological context from the discussion about the changes and stabilities.
				They take into account the tool's guidance.
1.6	0:00- 1:00	_		Continue
	1:00- 6:50	_	Associating changes and stabilities with the biology core idea	They discuss the aspects of the biology core idea in the phenomenological context. How to put those aspects in the speech of the characters. The vocabulary and kids' explanations of what they observe. The character "teacher" solves some of the kids'

				questions, letting them expose their reasons.
2.1	0:30- 3:00	Using TBs to interpret the phenomenon	Associating TBs with structures	They start socializing their individual understandings of the changes and stabilities of the phenomenological context from the last session (Figure 4).
				Anne and Ellen developed some models that might support teamwork in developing the explanatory model of their phenomenon (Figures 5 and 6).
	3:01-7:59		No codes	Video playing
	8:00-11:50	Using TBs to interpret the phenomenon	Identifying what each TB does	They come back to analyze the stability and change aspects to identify what each TBs does. For example, if the fly is always there. <i>This is a possible stability</i> <i>aspect</i> .
				They start considering aspects of the biology core idea regarding the relevant boxes for the model. They use mainly Figure 5.
	12:00-17:00	Integrating aspects of the biology core idea into the model	Identifying transformations inside the TBs	They start representing the mechanistic explanatory model integrating aspects of the biology core idea from the video (Figure 7). They plan to represent the "cycle" of the change in the plum generated by the organisms they identified: fly, larva, fungus. <i>They</i> <i>explicitly mention that these correspond</i> <i>to the TBs</i> .
2.2	0:00- 7:15	-	Differentiating change dimensions	They continue working on the model they started, emphasizing the inputs and outputs of the TBs. How are the TBs connected and the relationships among them? TB: Spore. How do the organisms take the energy from the fruit?
				At the moment, they are not referring explicitly to the content in the video.
	7:20- 8:10	Recognizing uncertainties	Identifying aspects to further detail	They write some questions they still have related to the products of some TBs.
	9:00-13:00	Integrating aspects of the biology core idea into the model	Identifying what each TB does	They interpret the phenomenon using the TBs they have already identified. Relationship between the boxes.
	14:00- 15:30	-	Characterizing exchanges of matter, energy, and information among TBs.	Explain the connection between the boxes

	15:30- 17:14	Specifying aspects of the core idea	Looking for extra information about the biology core idea	They look for additional information about the fly living cycle (from larva to fly) to understand how the "larva" is taking food from the plum to grow up. Contrast their TBs connection with one picture they found regarding this process.
2.3	0:00-5:50	Integrating aspects of the biology core idea into the model	Characterizing exchanges of matter, energy, and information among TBs.	Which organisms are important as boxes and the inputs and outputs of these. They have 4-5 boxes: the larva, fruit, fungus, the fly They are trying to "apply" the content to their TBs, such as assigning "scientific" names and functions. Larva and fungus: parasites and their function as consumers in the "food web."
	6:00- 8:00		No code	How to draw or label the model "parts" (e.g., P1 and P2 for both parasites)
	8:01-9:00	Analyzing online content videos	Revising biology core ideas with a focus on concepts	They refer to the content aspects that can "apply" to the transformation boxes they have. Try to include in the model/explanation the "scientific language".
				It is critical to support them in how "contrast" scientific meanings (in terms of the process beyond the words) and the interpretation of the phenomenon.
	9:01-10:13		No Code	Video playing
	10:14- 12:30	Analyzing online content videos	De- constructing biology core ideas	They focus on the aspects of the content they can use in the model/explanation.
	10:30- 12:50		No Code	Video playing
	12:50- 17:14	Analyzing online content videos	De- constructing biology core ideas	They are trying to evaluate which scientific words fits in the relation or processes in the TBs Are they "explaining" the KI or the model? Are they explaining the "concept" or the transformations underlying the natural phenomenon?

2.4	0:00- 9:26			They continue in the dynamic of watching the video and trying to explain with the "concepts" the organization they have done of the TBs.		
				It is favorable that they are trying to analyze in detail the video and evaluate the aspects useful for connecting the boxes and know which processes are occurring in each of the boxes. Nevertheless, they are using the "scientific version" to refer to the processes rather than "breaking down" these concepts and focusing more on the ongoing transformation. For teaching purposes, the idea is to transform the concepts (that teachers assume are understood not just known) into models/explanations that focus on the phenomenon's changes.		
	9:30-17:14	Integrating aspects of the biology core idea into the model	Identifying transformations inside the TBs	Final evaluation of the inputs and outputs of the TBs (fungus) and the comparison of the part of the fruit is healthy and unhealthy		
				I think this is related to the stability and change aspects		
2.5	0:00- 2:12	_	Differentiating observable and unobservable biological transformations	They continue evaluating the last details they are going to consider in the model- explanation. They differentiate the living cycles and processes in each of the parasites.		
	2:12-7:50		No code	Organizational stuff and Final comments. The video was useful. However, there are technical terms and no in TBs terms		
3.1	0:00- 1:54	- 1:54 Establishing the stages of the modeling-based investigation	Developing a sequence of partial questions	They summarize the partial questions:		
				1. How do fly, maggot, and fungus go inside the plum?		
				2. What happens in between the "parasite" and the plum? Exchange		
				3. Which consequences it has for the plum? Stay there or where they go?		
				4. What happens in extreme conditions with the "change" (in the fruit)?		
				Anne brought some models she created (Figures 8, 9 and 10) regarding the final model they have developed with the support of the pedagogical tool 2 (Figure 7). These models serve as material representations the group used to work on the third pedagogy and the support of the pedagogical tool 3.		

	1:54-16:33		Constructing partial explanatory	They develop the model for the second partial question (Figure 11)
			models	Focus on the plum. Inputs and outputs
	16:33- 17:14		No code	They talk about the final details of the model. Some parts of the model are quite productive for the model/explanation.
3.2	0:00-3:10		No code	They discuss how to represent the ideas they plan to explain with the third question and how to organize the planning table.
	3:10-14:00	Establishing the stages of the	Constructing partial explanatory	They develop the model for the third partial question (Figure 12)
		modeling-based investigation	models	Focus on the two organisms. Inputs and outputs of the fruit (environment to the fruit). Make decisions about what is important for the model/explanation.
	14:00-17:14	-	Generating a witting explanation	They write some ideas for the explanation related to the content (generation of the flies).
3.3	0:00- 3:50	_	of the biology core ideas	Continue. Work on the explanation that accompanies the model. Starts from the "cracks" that the fruit has and not from the tree, as they have thought in the beginning.
	3:50- 5:00		No code	Reading the tool
	5:00-17:14	Establishing the stages of the	Generating a witting	Writing for the explanation. Adding some details to the representation.
		modeling-based investigation	explanation including aspects of the biology core ideas	7:50 Anne explains some aspects to Kali. Kali wants to improve the final model.
				Ellen discusses some aspects of the explanation (no so good audio for them)
				9:10 again all
				(12:05-12:40 Pause)
				The aspects of the content is related to the generation of flies. To what extend this is related to the biology core idea, of interaction among organisms.
3.4	0:00- 10:44	-		Continue. How productive is it to include the generation of flies as part of the partial questions and in the partial explanatory models?
				<i>6:10-7:30</i> related to the biology core idea. Fungus and maggot live in the plum and take all from it.
				7:40 Anne explains something from the final model (Figure 7) to Kali.
	10:45-17:14	Evaluating the coherence and	Connecting partial explanatory	They discuss to what extent the partial models/explanations respond to the

-				
		appropriateness of the stages	models with the driving question	driving question. They compare two fruits good-not so good and return to the identification of changes and stabilities in their phenomenon. They ask questions like, what happens for example when there is not enough food from the fruit?
3.5	0:00- 3:00	_	Connecting partial explanatory models with the changes and stabilities in their phenomenon	Continue. Conditions for the change to take place.

Figure 1. Model of the plum phenomenon with the group's initial ideas



Figure 2. Representation of individual changes using Transformation Boxes

GE	Hzo & BRite (innem)	Unterstützendes Tool 1
2. Stellt die Veränderungen Boxen(TBs) dar. Figur 1 z diese, um alle Veränderu Kicht H 20 Naparial.	, um die es in eurer Geschichte r eigt Ausgangssituation und Endsituat ngen eurer Geschichte in einem erst 3 8 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9	nit Hilfe von Transformations- ion einer Veränderung. Benutzt ten Modell darzustellen.
Veränderung # 1	Veränderung # 2	Veränderung # *
Original "Figur 1 -	erste Versuche Veränderungen darzuste	ellen Baum stops du Plan



Figure 3. Representation of stabilities related to the identified changes

Figure 4. Anne's summary of the changes and stabilities of the phenomenological context

Unvelterifluse: Licht, 1/20, Mineralien aus dem Boder, Coz Planne, litz, Aalal unterschiedlich (Verfislarheit of dunker ( the thocyane) ( Fortigheit ) Ras Farbe, Form, Konsistent des micht flisses Geochmack. Enchogehal Warsergeralt, Starke gehalt Euchesgehalt, Made) Made won Ei > Zus Reife proton rife Fry the = noch -> linieie Pflaume Polyphenote (bes. Anth Vd. Reife Micht tury 3 Beachleuniz (Saul vlicle venel blan biblett .01 geerinet harsere Fricht Zink, lu Vescin CHE Kalzin weiche werde venij - alu cose gri bralle (Traubenzuche estable. hel Trophyse Fuctose 0,,101 00 SATIle Viel · Fuch Weiche Fucht Saccharose In lösen Warres Ballaststole) (durch Vie Jane Wenige Aroma Arouna Duftstoff Weißes Dufffilum. schutet die R. vor Aus Aroch mehs Vitamine (+ C!

Figure 5. Anne's initial interpretation of the phenomenon using TBs





#### Figure 6. Ellen's initial interpretation of the phenomenon using TBs

Figure 7. Group's mechanistic explanatory model of their plum phenomenon



**Figure 8.** Anne's version of the group's mechanistic explanatory model of their plum phenomenon



Figure 9. Summary of key aspects of the biology core idea in the mechanistic explanatory model



Figure 10. Partial explanatory model that represents the first partial question

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2 _ Duftstoffe a Information firs kay Blut	Warmeenergie
(Sviele)	. K _light
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- bohrt Loch in Pflaume Reife prozess	Wind
- kniecht hinein GEnergieum-	
-, ihre Umgebung, Phaume Vor	/ Wind tremsportier
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(Bisstelle d. Kaupe) Duftstoffe	Wirt
(>weniges)	Pitz (Monilia)
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#### Figure 11. Partial explanatory model that represents the second partial question



Figure 12. The partial explanatory model that represents the third partial question



Group/ Video clip	Line	Discourses	Highlighting	Coding	Material Representation	Episodes Characteristics
Group	1	<b>Ellen:</b> I got the name from the fungus. It is "Monila".	Return to the		Using individual-	<b>E1</b>
3/	2	Anne: So I wanted to ask you, I also found out.	organisms-	General overview	developed material	Identifying
2.1	3	Ellen: Yes, that's the right one. [both laught] That's it. And the	boxes	of the organisms'	representations that	which are the
	4	worms, or the maggots we have in the "damsons" [another specie	Fungus	roles in the central	support the teamwork.	TBs-organisms
0:30-	5	of plum], because they are no plums, they are "damsons". Yes,		change in the	These were created after	that play a
3:00	6	they are. [She refers to the representation she created after	Maggot or	plum:	working with the tool 1.	relevant role in
	-	working with the supporting tool 1. She has used TBs along the	worm	1- There is a tree with	Andrawine to south the (Minn Genanden) + Personal and	the central
	-	time to start organizing the understanding of the KI (Figure 1)] [1]		plums	Martin Care and Care	biological
	7	Anne: Oh! I wanted to ask you: "damson" or "plum"?	Decide plum	moths (or flies) that	The second secon	transformation.
	8	Ellen: Plum.	instead of	they use the tree as	The set of	This is a starting
	9	Hallie: But that's a kind of plum.	"damsons"	shelter.	(in The and in the and	point to identify
	10	Ellen: Yes, they are.		3- When is warm (and the fruits are ripoping)	(Ju) Bayes Kate Patters Walkstram von GU + Pptmane	the ideas from the
	11	Anne: The little ones, the easier to open?		they look for the fruits	Figure 1 Initial representation	them to detail the
	12	Ellen: Yes, that's the good ones. Yes, and those are What are		and lay their eggs.	using TBs along the time to start	aspects of the
	13	the names of these things? Oh, what's the name? Tree moth	Tree moth	4- Through the holes or	organizing the understanding of	changes-stabilities
	14	[while looking in her representation at time 1] [1a] They hibernate		cracks that the moth	the biology core idea [1]	(explicit in Julia K
	15	in a cocoon on the tree and as soon as it [weather] gets warmer,		fungus around can		comment)
	16	they hatch. So in spring [time 2] [1b]. And then they almost		enter and grow.		
	17	invade the flowers when new truiting bodies are forming and lay		5- There are also fungi		
	18	their eggs in there [time 3] [1c]. Through the puncture or this		inside the plum coming		
	19	puncture hole then the fungus has the chance to come in later		from all infected free.		
	20	[time 4] [1d]. Because it [fungus] comes through cracks, either				
	21	nail damage or noies in the peel and this puncture gives then the				
	22	A provide the second se				
	25 24	fungue are found				
	24	Hallio: Ok				
	25	Hame. OK				
	-	[1:46]	Fungi in the	Eungi from trag or		E2 Devising CUS
	26	<b>Anne:</b> So I only read that with injury if somehow you cut off or	tree	in air (stability		related with the
	27	cut back the trees and then do not refine them, then the fungi will	400	aspect)		TBs organisms
	28	come in.		uspeer)		(fungus and

## 9.3 Appendix C. Example of analysis of pre-service elementary teachers' discourses using PV's discursive practices

	29 30 31	Ellen: Yes, exactly. Anne: But when the maggot comes [pointing on Ellen representation] [1], then it makes itself.	Maggot in fruit	Maggot (change)			maggot respectively)
	32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 - - 49 50	<ul> <li>Ellen: That makes the injury itself. Then I figured out that stability and changes are about the same, but I completed that [1e]. [While reading from the representation] [1f] So the fungus is already on the tree or is just in the air and spores can be distributed.</li> <li>Anne: Exactly.</li> <li>Ellen: They come by the air just everywhere.</li> <li>Anne: The spores are already in the air from other trees.</li> <li>Ellen: [nods] Maybe there's something on the plantation.</li> <li>Anne: Infested.</li> <li>Ellen: It [plantation] is infested and so the fungus can spread and then comes through rainfall or simply by air contact outside the fruit.</li> <li>Anne: Do we want to make a big one [model] again?</li> <li>Ellen: We can do that too, yes.</li> <li>Hallie: So then do one together.</li> <li>Anne: Exactly. Definitely, yes. [leafing through] Hmm, yes. Oh! Do we that together first and then we watch the video or do we want to watch the video first?</li> <li>Hallie: First we watch the video.</li> <li>Ellen: Only the video, if we have new ideas, then we can bring that indirectly with it.</li> <li>[2:52] ()</li> <li>[3:06-7:42] Watch the content-based video. They decided to watch the whole video before start constructing the model in spite</li> </ul>		<ul><li>Written in the MR: S: fungus, tree, location, conditions of plums</li><li>CH: seasons, plums, and tree moth development</li></ul>			
Group 3/ 2.1 8:00- 11:47	51 52 53 54 55 56 57	<ul> <li>Anne: Because that's the case with the fact that the host is always bigger than the parasite.</li> <li>Hallie: Hmmm. Again, a question about the fly. So the larva then develops into a fly, does the fly stays near the plum and the tree? Or is it flying?</li> <li>Anne: I do not know that.</li> <li>Ellen: I did not hear about it either.</li> </ul>	Role of the fly		Using developed representations support the	individual- material that teamwork.	E3 Identifying which are the boxes + What do the boxes do

again for safety to lay an egg. So there is always only one egg in a so	lies do it for afety to lay their	J. Plane View standard allower ingeling !	
65 plum. Fli	afety to lay their	TIDE MATL MANAGE	
66 Hallie: Hmm. Ok. sat	and thus	Figure 2. Initial representation	
67 Anne: Yes.	ggs and thus	using content from video to	They do not give
68 Hallie: They [flies] already know how they do it.	nsure their	make some decisions about the model	a role to the tree
<b>69 Ellen:</b> And that's not only with plums. It also possible with	Irvival. It	mouch	as they initially
70 cherries	appens with other		have considered
71 Anne: Exactly Interview of State of State Sta	uits.		(II the fungus comes from it)
72 Enen. And stuff like that, that's in a lot of 73 Anne: Fruit trees and stuff like that			They decide to
73 Filen: Also with apples and stuff like that			start with the
75 Julia P: Which sites [in the internet] do you have?			fruit. The fly
<b>76</b> Ellen: Different. But something with "garden friends" was there Sources they			and fungus are
<b>77</b> and I have various forum posts use to			part of the
78 Anne: That's exactly how to garden portals were. understand the			surroundings of
79 [9:13-9:27] They decide who draws role of the			the fruit, and
80 Anne: First, we need the tree. How do I represent it? [She refers organism	ole of the tree:		thus they can
81 to the representation she created after working with the supporting boxes.	1s already		interact.
- tool 1. As they know on advance the video she has used some	he tree is a shalter		
- aspects of the content from it to make some decisions about the Role of the tree for	ne nee is a sheher		
- model (Figure 2)] [2] Do we just take that as an edge piece, that	n lungi.		
<ul> <li>82 We have the branch of how? [looking at her model] [2a].</li> <li>83 Film: Somewhere under the back, the function overwinter Tree, function</li> </ul>			
- Hallie: So only half the tree like that [hands movement]			
<ul> <li>84 [9:47] [Anne starts drawing the big model] [3]</li> </ul>			
85 Ellen: So we can take the tree affected by the fungus or just in the			
- air, because that's easier, when the tree is already affected.			
86 Anne: Just for clarification: The fungus is everywhere in the tree? Fu	ungi: 2		
<ul><li>87 Because I wasn't sure, if the fungus is only in the fruits or also in</li><li>88</li></ul>	ossibilities:		

89	the whole tree. I once read that you can stop the affection of the				- In the fruit and	
90	fungus by cutting the branches and taking the fruits off.				can affect later the	
91	Ellen: Is not necessarily like that. It depends on how far the				tree.	
92	fungus has spread. Because if that has packed itself on the tree,				-Coming from the	
93	then you can actually only fell it. So cutting back should help and				affected tree.	
94	harvest the whole fruit from the tree when you realize that they					
95	are infected, but you have to do that for years and hope it works.				They decide the	
96	There is no such thing as a sure remedy for the fungus.				fungus starts in the	
97	Anne: And is it possible that the fungus is in the fruit first and not				fruit, not in the	
98	going to affect the tree? So that the fungus is only in the fruits?				tree.	
99	<b>Ellen:</b> The problem is that the tree doesn't repel the fruits by	Role	of	the		
100	itself, as I originally understood. One source also says that the	fungi				
101	tree has not like a natural "repulsion reaction", at least not					
102	that powerful and therefore, the fungus can actually expand					
103	well. So firstly, it's on the fruit and then also the tree will be					
104	affected.					
105	Anne: So if you don't cut off the affected fruits, the tree will					
106	follow.					
107	Ellen: Therefore, one should shake off everything.					
108	Anne: So it begins in the fruit?					
109	<b>Ellen:</b> Yes, so initially, it begins in the fruit. Then it goes over the					
110	tree.					
111	Anne: Ok, so we start with the fruit!					
112	[11:47]					

Group	114	Julia P: [While drawing] [3a] So a few thick branches, thin		Creating their own	E4
3/	115	branches, plums, which we then enlarge.		material	Identifying
2.1	116	<b>Ellen:</b> Do we build the model with all the things in it?		Representations (complex	structural
	117	Anne: Yes, by this cycle, because the single representations we	Which are the	model)	aspects of the
12:00-	118	already got [referring to the representations of the individual	boxes.		transformation
17:13	119	changes they made with the supporting tool 1]. Or do you just			
	120	wanted the cycle without the tree?			Delimiting boxes
	121	Hallie: No, I'd depict the tree within the model, because it			and their
	122	belongs to the process of affection.			environments
	123				

124	Anne: [While drawing] That's our cycle [3b]. The plum is the	Focus on the	
-	center of our model? [drawing a big plum in the center] [3c]	plum	
125	[looks at her model] [2b]		
126	Julia K + Hallie: Yes		
-	Julia P: We just do not have the stages [of the change identified		
-	with the support of the tool 1: from fungus inside the plum to		
-	decay process] here, but we'll have to see how we do it [represent		
-	the cycle in the model].		
127	Julia K: We can do that extra.		
-	Julia P: So there's the fungus which is in the air with the spores	Environment of	
128	[drawing fungus and spores in the air, around the plum] [3d]	the TB-fruit:	
129	<b>Ellen:</b> Do we have to do the air with oxygen particles and such?	fungus and	
130	Anne: And then that's our oxygen [draws oxygen (triangles)	oxygen	
-	around the plum] [3e]		Interrelations
	Anne: The fly, better the maggot is already hanging on the tree,		maggot-fruit
	you said? [draws small maggots in one branch of the tree] [3f]		
131	And how does the maggot get there?		
132	<b>Ellen:</b> The maggot pupate on the tree and crawl to the fruit by using		Inputs of the TB
133	the branch.		fruit (maggot)
134	Anne: [While drawing] [3f] So this is the initial stage of the larva		
135	The larva, I depict it a bit bigger here [in the surface of the fruit]		Relation spores-
136	[3g], goes that way in, which represents our first transformation		fruit (because of
137	box [draws a square to empathize the larva is a TB] [3h]. Then here		the hole the
138	[in the surface of the fruit] evolves a hole. [3i]		maggot made)
139	Anne: Well the spores come from here [the air], but actually they		Inputs of the
140	are everywhere [drawing more spores around the larva and the		maggot ("the
141	hole] [3d] () What do we also got? The maggot also needs		magot also needs
142	oxygen [drawing oxygen (triangles) around the maggot] [3e]		oxygen)"
143	Ellen: Yes, that's right. The plant needs this also for		Inputs of the Plant
144	photosynthesis.		$(O_2 \text{ for })$
145	Anne: Yes. So it's also in the fruit? There's more oxygen in the air,		photosynthesis)
146	isn't it? [drawing oxygen inside the box they drew to empathize the		Characterizing the
147	larva is a TB and around the fruit] [3e] What's left? Carbon		"inputs" of the
148	dioxide [3j] and water [3k] [draws around the larva]And lightI		truit (spores, light)
149	draw it in between! [31] With it [light] are all things which goes in		and outputs
150	the TB [maggot].		(oxygen, carbon
151			dioxide, water)

And and a second s

Dimensions of the change (Matter: substances and energy: light)

Figure 3.. Final explanatory model articulating the aspects of the key ideas from video

Materializing organisms as boxes. [3a] tree [3c] plum [3d] spores in the air (input of the plum) [3f] maggots (larva) on the tree (initial stage) [3g] bigger larva [3p] spores inside the plum [3s] maggot inside the plum [3u] egg (before it hatches inside the plum) [3v] fly [3w] egg (laid by the fly 3g, in the surface of the plum)

Materializing the dimensions of the change A. Depicting substances (Matter dimension)

	152	(they use the word maggot and larva to refer to the same TB- organisms. The second stage of the living cycle of the fly)			<ul> <li>[3e] oxygen in the air around the plum (input of the maggot)</li> <li>[3m] oxygen (output of the plum and input for maggot and fungus)</li> <li>[3j] carbon dioxide (output of the maggot)</li> </ul>	
					[30] carbon dioxide (input	
					of the plum and for the	
		<b>Anne:</b> What goes out [from the fruit] right here?			maggot inside the plum)	
a		<b>Ellen:</b> Well, the products of photosynthesis.	Outputs of the		[3k] water (output of the	E5
Group	153	Anne: So, Oxygen, Water, what else? [draws oxygen (triangles)	TR fruit		maggot)	What are the
3 2.2	154 155	close to the surface of the fruit were the maggot is] [3m] So die	(oxygen, water)		plum and input for the	substances
2.2	-	triangle [symbol they use to represent oxygen].			maggot)	Stability and
0:00-	-	Julia K: There you can also get an arrow from the [fruit]. Oh			[3q] nutrients (input of the	change (amount
17:14	156	right, we'll do it. Really good. [3m]			maggot, output of the	of oxygen)
	157	oxygen] [3n]			plum)	
	4 50	<b>Anne:</b> [while drawing] So oxygen I think about the quantity. It's			[3r] waste product of the	
	158	more, isn't it? [drawing more oxygen (triangles) close to the surface			Iungus [3t] feces (output of the	the
	- 159	of the fruit where the maggot is] [3m] Because it's a product of		Use the concept	maggot)	transformations
	160	photosynthesis.		"photosynthesis"	[3y] nitrogen (from the air,	as <b>outputs -</b>
	161	Ellen: Yes, I agree with "more".		to know which are	input of the maggot)	inputs in the
	162	<b>Anne:</b> So here it is relatively much [oxygen] [3m]. <b>Hellio:</b> But do the fruits do photosynthesis? Isn't it the tree which		the inputs and	[3z] glucose (output of the	main TB fruit
	163	do so?		outputs of the	plum in the "normal"	
	164 165	Anne + Ellen: Yes, it's the tree.		II uII.	ripening process)	
	105	Ellen: The tree by its leaves.			(50) gracose (output of the fungus)	
	167	Anne: So it's approximately the same. So, we have to see how			[3a'] starch inside the plum	
	168	much. So, what else gets out? Water. [drawing some arrows from	Outputs		(input of the fungus)	
	169	the truit to outside [3n] First, that [carbon dioxide] [30] is going	Torrest		[3c'] tannins (output of the	
	170	Inside [to the inuit]. The maggot too [3g]	input	A amonto of the	plum)	
	171	Ellen: Right		content knowledge	P. Energy dimension	
	172	Anne: The sugar is just arising and becoming more and more.		(nutrition, sugar) +	D. Energy unitension	

174	Ellen: But the sugar isn't out, it's still inside.		aspects of TB	[31] Light (input of the	
175	Hallie: yes, it develops itself.		logic (outcome of	maggot)	
176	Anne: There is a lot of starch, I just read [in an additional source		the process, from		
177	of information, different to the video]. So the quantity of starch		CO <sub>2</sub> )	Materializing features	
178	lowers while the fruit gets ripper and the quantity of sugar rises up.			[3b] cycle (interaction	
179	What else? Circles were CO <sub>2</sub> [while drawing more carbon dioxide			among organisms with the	
180	around the maggot] [30], a little bit of everything which remains, is			plum in the center)	
181	always getting out, but less.			[31] note in the fruit	
182	Ellen: True.			[3n] square to emphasize	
183				(nlum magget inside	
184	[1:49]			(piulii, inaggot inside,	
-	Anne: So the spore gets inside.			maggot going in, tungus-	
-	<b>Ellen:</b> They still remain inside and don't come out again.		Spore as a TB. But	spores inside, fuligi on the	E6
185	Anne: [while drawing spores inside the fruit] They stay inside and	Input of the TB	the fungus is the	surface)	Conceptualizing
186	expand. [3p]	fruit (spore)	TB in direct		the
189	Ellen: Yes, that's right.		interaction with		transformations
190	Anne: [while drawing] should we have more of those here [spores]		the fruit.	Using individual	as the flow of
191	[3p]?		Delimit the	representations to support	matter among
192	Hallie: So are those however other TB? The spores in the plum?		exchanges	the creation of the group	TBs-organisms
193	Anne: So the spore What it takes from the plum and what it gives		between fruit-	models	
194	to the plum. [while drawing more spores] [3p] Or maybe what the		maggot and fruit-	models.	
195	maggot gets from the fungus. So I don't think the maggot itch very		fungus.	Station . Theread in a march high the Mandien and dem John for	
	much.		Input of the TB	(Very Carrier and Carrier Construction) ( Touch flow)	
107	<b>Ellen:</b> The main point is that the maggot still gets nutrition from		fungus and	Automatication ( Wilson Real ) Since a provide a strain a	
196	the plum.		maggot.	sended one (and rive a short Fundal) And have been a short for the short	
197	Hallie: exactly.			The second secon	
198	[2:30]			Ver Starie Succession Register Succession	
199	Anne: Are they in competition? Fungus and maggot?			Davies have been for the second of the the there is the	
200	Ellen: No, both just take the energy and the nutrients of the plum			Figure 4. Initial representation	
201	because of the need to develop further. So the fungus needs to		Related to the	to start organizing the	 F7
202	develop to get outside and release the spores to save is life cycle.		aspects of the KI:	understanding of the KI (focus in	E/ Concentuelizing
-	So the things both parasites need, are enough for both of them.		explores	the S-C aspects in three different	the
203	<b>Anne:</b> But the only thing is that the fungus doesn't like the oxygen.	<b>T</b>	organisms'	suges of the change)	transformations
204 205	<b>Ellen:</b> But I don't think that there is still a lot of oxygen in the plant.	Input of fungus	interactions with		as the flow of
205	Anne: But the maggot needs oxygen for its surviving.	and maggot	their physical		
200		(energy)	environment,		TDa arganiana
207					i bs-organisms

208	Ellen: There is a little conflict here. Or it does work out because	which in this case	
209	the maggot takes the oxygen and so the fungus doesn't get in touch	is a TB.	
210	with [for the fungus] life killing gas.		+
211	Anne: We can reading this again.		Develop the
212	Anne: Ok. So [the maggot] needs the oxygen from the plum		characteristics of
213 214	alum to the hey they denieted for the magget [2m]		Box as an
214 215	pium to the box they depicted for the maggot [511].		Environment
213 216	Hallie: And the nutrients		
210	<b>Anne:</b> O <sub>2</sub> and nutrients. [while drawing some squares to represent		
218	the nutrients] [3g] And all the vitamins and proteins, which are in		
219	[the plum]. So later, we can verify what is all that. Ok, So we need		
-	again a Box I'll draw the box green to emphasize it. So the next	Attempt to	
220	box is, fungus and plum '. [drawing squares to emphasize the boxes	understand what is	<b>E8</b>
221	over the representation, in the fungus and plum] [3h] The fungus	going on with the	
222	takes	transformation of	The idea of the
223		the fruit. (KI	flow of matter
224	(Internet )	+TBs)	strongly
225	TTT A TANK	Other inputs of the	shongry
-	32 34	maggot (nutrients,	
226		water, oxygen).	
	Liten + name: yes, sure. Julio D. Ok the fungue takes		
	Film: Nutrients [3a] and also water [3n]		
	<b>Anne:</b> Water what else does the fungus need for growing?		
	Humidity but that's water` [drawing arrows from the water and		
2.2.7	nutrients]		
228			
229	[5:12]		
230	Anne looks in at the representation she made individually before		
231	the meeting [2c] [5:21] Ellen looks in her representation [1].		
-	Hallie: Does this depends on the light? The dissemination		<b>_</b>
-	Ellen: It also needs light, so the energy		 Е9
-	Ellen: So do you mean the dissemination of the fungus? Later as	Energy dimension:	<b>E</b> 22
-	spores or the fungus in the plum?		

-	Hallie: The fungus in the plum. Actually, the transition from the		Fungus use the	Conceptualization
232	spores.		energy from the	of biological
233	<b>Éllen:</b> No, it's in the plum, so it doesn't matter. The essential point		plum for	transformation
234	is that the plum gets enough energy to grow and exist. So indirectly,		"reproduction."	("growing") is
235	the spores already depend on the fungus but that's not as much		The plum is using	getting strong
236	as the plum.		the energy from	(not only about
237	Anne: The fungus doesn't need sunlight.		the sunlight	outputs but the
238	<b>Ellen:</b> Yes, the fungus just needs the energy, which the plant is		6	consequences)
239	getting from the sunlight.			Dimensions of the
240	Anne: Okay, so I write down "energy '[in the representation] [3].			change: energy
241	The plant also needs it. We have first energy, right?			and information
242	Ellen: Hmmm			
243	Anne: At least from the light. I write this here at the top "caloric		Information as a	
244	energy" [31].		dimension of the	
245	Anne: Ok, what do they have as a waste product?		change. In regard	
246	Julia K: Do you mean the fungi? Good questionI am thinking		to the interaction	
247	about it. [Anne draws some dots going outside the box fungi] [3r]		between fungus	
248	Anne: So the maggot seems not to be impressed.		and maggot. There	
249	Ellen: And would the waste products given to the plum or would		are no exchange of	
250	those direct expelled?		information	
251	Anne: Ahh. Do you mean if those here get out?		among them.	
252	<b>Ellen:</b> Yes, if the waste gets out completely. If the fungus grows,			
253	then it can			
254	Ellen: Yes, when the fungus get bigger would give it to the			
255	environment.			
256				
257	[7:16]			
258	Anne: I'll write down our questions.			
259	Ellen: [While writing] So, 1 question was waste products of			
260	fungus.			
-	Anne: I got one more question: If the fungus is disrupted by the		Aspects that	
-	oxygen, but we can research this later. And if the maggot and the		demand a "deep"	E10
261	fungus[Ellen continues writing]		understanding of	Identifying the
262	Hallie: If they compete or not.		the aspects of the	aspects of the KI
263	Anne: Or if both eat each other.	Questions they	KI:	or the TBs
264		still have	-Relation maggot-	regarding the
265			lungus	changes (initial

266 267 268	[8:10] Anne: [While writing on the representation referring to water, oxygen, carbon dioxide and spores] Well, this is the matter [substances] which goes in			Aspects to deep in the TB logic: - Dimension of the change: outputs of the fungus	and final states of the dimensions) that the need to detail.
269 270 271 272 273 274 275 276 - 277 278 279 280 281 282 283 284 285 286 287 288	<ul> <li>Hallie: Do we need another TB for the maggot in the plum?</li> <li>Anne: Yes, we can do so now. [Draws] [3s] Does it also go out the plum?</li> <li>Ellen: No actually not. But later, when the maggot pupates itself.</li> <li>Anne: Well, I'll do [the maggot going out] for later. [Draws a square to emphasize the maggot inside the plum is a TB] [3h]</li> <li>Hallie: So it [maggot] grows in the plum, we said. From the pupation on the tree, it goes into the plum, grows, and then goes out again.</li> <li>Ellen: Right, that is the cycle.</li> <li>Hallie: Does it pupate again and become a fly?</li> <li>Ellen: Or deposits the eggs in the next [plum] and dies anytime.</li> <li>Hallie: So it gives off eggs.</li> <li>Anne: Only one.</li> <li>Hallie: So it gives off the egg. [All laugh]</li> <li>Ellen: And it takes the energy from the plant, actually out of the plum.</li> <li>Anne: And the nutrients also. It also uses up the oxygen. [draws the inputs for the box maggot] [3m] [3q]</li> <li>Ellen: Of course oxygen and water too.</li> <li>Anne: [While drawing] So we take two [triangles that represent oxygen] [3m] and water also two [representations of water] [3n].</li> <li>Hallie: Does it [maggot] also consume CO<sub>2</sub>?</li> </ul>	Return to organisms boxes Focus on maggot	the as the	Maggot: - Is inside the plum that is hanging on the tree. -grows inside the plum. -goes out (when it is big enough) to continue it life cycle (to fly and lay more eggs in other plums). Inputs: energy, nutrients, oxygen from plum, maybe carbon dioxide even it doesn't need too much.	<b>E11</b> Identifying which are the TBs-organisms that play a relevant role in the central biological transformation. Differentiating the levels of the transformation (maggot on the surface and inside the plum) and the dimensions of the change
288 289 - 290 291 292 293 294	<ul> <li>Anne: A half circle, then [writes on the representation] [30]</li> <li>Hallie: We take half a CO<sub>2</sub> molecule.</li> <li>Anne: A half circle, then [writes on the representation] [30].</li> <li>Hallie: So release of CO<sub>2</sub>.</li> <li>Ellen: This is the waste and then it also releases feces.</li> <li>[Anne draws feces going out the maggot] [3t]</li> </ul>			Outputs: eggs, carbon dioxide, feces.	Energy and Matter dimension

295	Ellen: So the little spots are the waste in general [writes in the		
296	legend of the representation]. [3r] [3t]		
297	Anne: And who bothers with the feces?		
298	Ellen: The people who want to eat [the fruit].		
299	Hallie: So I think the fungus isn't really interested in the feces.		
-	Ellen: I'll just write it down. [While writing] Does the feces		
300	bother?		
-	Anne: Because you can eat that too.		
301	Hallie: Yes, that's good. And we need another TB for where		
302	the eggs lie? [Anne: Nodding] We do not have enough color,		No relation
303	here we have yellow for the egg.	Possible	fungus-maggot
304	Anne: [while drawing an egg inside the plum] [3u] Okay, but	relation fungus-	
305	doesn't it get the same as [maggot] So do you mean when it	maggot	
306	hatches? Does it [egg] get the same nutrients as the maggot?		
307	Hallie: Do we put it to the maggot? [Pointing on the model].		
308	Anne: We can do it that way [draws lines from the maggot going		
309	inside to the egg and then to the maggot inside. This connection	-	
-	refers to the same interaction of maggot, egg, or larva with the	Focus on the	<b>T</b> . <b>T</b>
310	plum] [3g] [3u] [3v] Okay [pointing on the model] I just think	egg as TB	Inputs and outputs
311	about the pupa, does the maggot drill a hole? How does it get in?		are the same as the
312	<b>Elien:</b> Eitner it eats a noie in the skin. Anyway, it breaks through		maggot.
313 214	the fruit peel.		
314	A new The hole must be bigger!		
-	Film: Perfect! But then still missing the		
- 315	Hellie: The fly we also put on the outside [of the plum]		
315	Anne: Ves, and here [3u] we put the egg		
310	<b>Filen:</b> But I think it's actually not a real fly. If I understood it in		Maggot goes in
318	the right way, it's just something like a little worm.	How egg or	through the fruit
319	Hallie: Like an intermediate stage?	maggot go in?	peel.
320	<b>Ellen:</b> So there was a year, when we had a huge plague of them.	88 8	P · · · ·
321	These were so small, green, so big [shows with fingers about 3-4		
322	cm.] worms.		
323	[13:21-14:04] [Anne looks in her representation (Figure 2) [2]		
324	and another representation she has made after working with the		
325	supporting tool 1 with the focus on the S-CH aspects in three		

**326** different stages of the change (Figure 4) [4]]

327				
	[14:05]			
	Hallie: [While pointing the model] The fly, wait (), the pupated			
-	maggot goes in here [inside the plum], then it lays the egg.			
-	Anne: No, it hatches, doesn't it?			
-	Hallie: So we got the line [Julia P draws to connect the maggot			
-	going in [3g] and the egg [3u]] to the egg and then it hatches-			
-	[3s].			
-	Anne: That's actually the new one, so they don't have a thing to			
-	do with each other.			
-	<b>Ellen:</b> So here the egg [inside the plum] [3u] arises and the new			
-	[fly]			
328	Hallie: Then the fly?		Different stages of	
329	Ellen: And then it just comes out here [of the plum]. If it's going	Focus on the	the life cycle of	
330	to be a fly, I don't know yet.	maggot- egg-	the fly:	
331	Anne: So I thought	fly		
332	Hallie: Or is that because otherwise		Fly: lay eggs over	
333	Anne: Pupa turns into the maggot, because it breaks through its		The tree	
334	shell and then it gets outside. Then it's a fly or else and again lays		larva The larva	
335	down an egg.		crawls to the fruit.	
336	Hallie: [While pointing the model] That's the question of whether		The larva (maggot)	
357	it will lay the new egg here [in the surface of the plum] or if the		makes a hole in the	
338 220	hew maggot deposits it [inside the plum]. Alterwards a new one		fruit and go inside.	
339 240	natches, it gets outside and becomes a fiy, pupates again on the		Inside it pupates	
340 241	Anne. I'd saw it's like you said		receiving nutrients,	
241	<b>Film:</b> So it gets in [magget] it [fly] love the aggi [agg] betches		from the plum	
342	and again becomes a pupa		Inside it hatches and	
343	Hallie: So new egg in right. So that's the way you did it		goes out (new fly)	
345	Filen: That's right ves			
346	<b>Anne:</b> The fly is here [outside the nlum]			
340	Hallie: Right that's the new TB or is it a new? Is it important			
348	for us?			
349	Anne: Only for lying the egg [draws a fly] [3y]			
350	Hallie: Or for the re-pupation.			
351	Anne: So the fly lays its egg.			
352				

**E12** Conceptualizing the transformation in different levels Describe the change inside, outside and at the surface of the box plum.

	353	[15:43]			
	354	Ellen: Do we can google it?			
	355	Anne: Yes. [activating notebook + google]			
	356	Hallie: Cycle of pupation.			
	357	Anne: I just try to google "maggot".			
	358	Hallie: "maggot" cycle, maybe that will work out.		Fly as TB is just	
	359	Anne: Life of the "maggot ". Where do you read that?	Fly as TB	for lying the egg.	
	360	Hallie: Just google it.			
	361	[0:00-0:58] They look for some images of the life cycle of the fly,			
	362	from egg, larva (maggot), pupa and adult fly). They want to be			
	-	sure about which boxes are important for understanding the			
	-	interaction plum-fly that is determining the change in the fruit.			
	363	Anne: [While reading from the internet source] Hmm so that's on	Look for		E13
	364	the tree and yet [the fly] lay in the fruit, we've read that right, in	information		Conceptualizing
	365	the fruit its egg. Then the maggot hatches. So this is not here in	regarding the life		what do the
	366	[pointing the egg inside the plum in the model] [3u] but the egg	cycle of the fly		boxes do and
	367	goes in.			connections
	368	Hallie: [While pointing in the model] [3u] Hmm. But that [plum]			among them
Group	369	must be somehow at least nibble.			Change in their
3.	-	<b>Ellen:</b> Yes [nodding] that must be so, there must already be a hole			initial ideas (roles
Tool	-	in, so that the egg can go in. So that the egg can be into the fruit.			of the TBs-
2.2.3.	-	Hallie: Exactly.			organisms)
0:00-	-	Anne: So that's the fly that carries it in.			E I
5:43	370	Hallie: Hmm.			From larva
	371	Anne: So theoretically this [pointing the maggot going in] [3g] is			tree (crawling) up
	372	our fly [they change the maggot going in for a fly laying eggs].		Fly lay the eggs	to the fruit to the
	373	<b>Ellen:</b> Hmm. We can still paint wings for it [3f]. Then we have		directly in the	fly laying the egg
	374	finished our fly.		plum. The larva	directly in the
	375	Anne: Exactly. [While drawing] That's our fly [3g].		does not come	plum.
	376	Hallie: It lays its egg and out of it comes the maggot.		crawling from the	
	377	<b>Ellen:</b> Shall we draw that egg down there [while drawing an egg		tree.	
	378	in the surface of the plum] [3w]?			
	379	Anne: Exactly.			
	380				
	381	[1:53]			
	382	Hallie: What does it [resource in internet] mean by the cracking?			

**Ellen:** That, there are two different cycles.

\_\_\_\_\_

384	Anne: Yes. So that's what we said with Spring and			
385	Hallie: With fall, all right			
386	[Anne looks for more pictures on the internet].			
387	Ellen: Yes, it's a bit disgusting.			
388	Anne: Look, here's more. Ah, that's different. But look here is			
389	still a moth.			
-	Hallie: Looks more moth than fly			
390	Anne: So definitely have the [Draws wings to the new fly]			
-	[3g].		Understanding the	
-	Ellen: Also down wings. Nice		change inside and	
	Hallie: The proportions are just not right [laughs]		in the surface of	<b>E14</b>
391	Ellen: No matter. That's not what it's all about.	Deep	the plum regarding	Deep
392	Anne: Well, good.	understanding	the life cycle of	understanding of
393	Ellen: We did that well.	of the life	the fly (does the fly	the relation
394	Hallie: So here's the right one [pointing the fly] [3v], when it goes	cycles of the	lays the eggs inside	between plum-
395	out.	fly	or on the surface of	fly
-	Anne: Exactly, as new. That's why we left a good loophole		the plum?)	
396	[draws an arrow from the maggot inside the plum [3s] to the fly			Identify which
397	[3v]].	Features of the		boxes play a
398	Hallie: Great.	fly		relevant role in
399	Anne: Hmm, exactly		A1.1 1 .1	the change of
400	Hallie: Do we actually see it [fly] as a transformation box? Not		Although they	the plum.
-	really, right?		recognize the fly	
401	<b>Ellen:</b> From then on, it [fly going out the plum] [3v] does not		as TB this is not	- To what extent
402	interest us anymore.		so relevant for the	the fly is
403	Hallie: Exactly, from ahead [Ellen incomprehensible parallel]		after it good out	important for the
404	Ellen: The same cycle starts from here.		, after it goes out	model/explanati
405	Hallie: Ok.		bit the pittin (they keep the focus on	on. (Does the
406	Anne: Well, this is where we can get away, theoretically.		the change of the	plum contributes
407	Ellen: The tree with the foliage.		nlum rether then	and/or make part
408	Anne: That they [flies] are not on it. Or am I wrong?		on the fly life	of the fly? It serves
-	<b>Ellen:</b> No, no, they're already on. They pupate over the winter to		our lie it salf)	as a shelter and
-	survive.			provides food to
409	Hallie: And then hatch in the spring and go in.			the eggs, larva,
410	Anne: Oh, the one that flies is this [the one [3g] coming from the			and pupa-Aspect
411	larva hanging on the tree [31]			of the KI)
412	Hallie: Hmmm			

413	Ellen: Exactly.		
414	Anne: Then again [draws an arrow to connect the fly going out		
415	the plum [3v] with the larvae hanging on the tree [3f]]		
-	Hallie: Exactly. It goes back to hibernation. [laughs] Great.		
416	Ellen: Exactly, then we have to classify		
417	Anne: Exactly		
418	Ellen: What are the names of these things?		
419	Anne: What do you mean?		
420	Ellen: What kind of parasite they are.		
421	Anne: We'll do it afterwards.		
422	Hallie: We can do that with the video.		
423			
424	[4:10]		
-	Anne: One more question: Do we need another transformation		
425	box with the fungus going outside? And the plum started to drip.		
426	Hallie: The fungus also appears on the peel of the plum, is it not		
427	only inside?		
-	Ellen: No, the fungus also goes outside		
428	Hallie: Yeah, that's right, so we definitely need one more TB	Referring to the	
429	where the fungus probably looks like.	video to deep	
430	Anne: So the fungus oh well, then that's no longer spores ()	the	
431	[draws a fungus on the surface of the plum] [3x]	understanding	
432	Hallie: Exactly	of the relation	
433	Ellen: [While pointing in the model] That will be from here too	plum-fly	The fungus is also
434	[from the spores inside the plum [3p] to the fungus on the surface		on the surface of
435	[3x]] [Anne draws an arrow that indicates the fungus on the		the TB plum.
-	surface comes from the spores inside the fruit]		From there
-	Hallie: That's the right fungal attack. So the external also And	Fungus as TB	releases spores
436	would it be another TB?	(going from	into the air.
437	Anne: Yes, that still has to be one.	inside to the	Inputs: energy,
438	Hallie: And he probably releases new spores in the air?	surface of the	nutrients, water
439	[Anne draws a square to emphasize the fungus is a TB [3h]]	TB- plum)	from the plum
440	Ellen: Exactly. The fungus gets the energy, nutrients, water, and		Outputs: spores and
441	all out of the plum. Setting free spores and after that, it gives out		waste products.
442	the waste products.		They have 5 hoves:
443	Anne: Okay		the larva (maggot
444	<b>Ellen:</b> So many boxes, we got 4 and 5 now.		ine fai va (inaggot

\_\_\_\_\_ E15 Conceptualizing the transformation on different levels Describe the changes in the plum inside, outside, and at the surface in relation to the
	- 445 446 447 - 448 447 - 448 449 450 451 - 452 453 454 455 456	[5:43- 8:00] Writing some labels in the representation. For instance, host for the plum, P1, and P2 to indicate which the parasites are. P1: Fly maggot and egg. P2: spores and fungi. Anne writes in the arrow that connect the fly going out the plum to the larvae on the tree: "second cycle for laying eggs, one egg per plum" "survival"		inside), spores, plum, fungus, and the fly (laying eggs) They are trying to "apply" the content understanding of the relation plum- fungus and plum- maggot or fly. Both are receiving matter and energy from plum.		presence of the fungus. Develop a better understanding of the biology core idea (regarding the phenomenon relation fungus- plum and fly- plum: Somehow plum is allowing the survival of the fly)
Group 3/ 2.3 8:00- 9:00	457 458 459 460 461 462 463 464	<ul> <li>Anne: So we got producers and consumers as terms.</li> <li>Ellen: Yes, the both parasites are the consumers, but we have to distinguish them a bit more in detail, because both of them stays the majority of their lives inside, but not the whole life.</li> <li>Anne: That's right, because both are coming out to search for a new host. So that's the one consumer [label in model sketch for the fly and maggot] [3] and this is the second [label for the fungus] [3].</li> <li>Ellen: The plum is the producer [label on top the plum] [3].</li> </ul>	Which aspects of the content from video are relevant to understand the connection among the boxes	Differences between the maggot and the fungus in relation to the fruit.	Labels of consumers to maggot and fungus and producer for the fruit.	E16 Revising ideas from the video with focus on the concepts (consumer and producer)
Group 3/ 2.3	[Repro [9:00- Video at sac their o Germ	oduce the video to identify more aspects of the content productive for the mo <b>10:10]</b> <b>o transcript:</b> "The term parasite comes from ancient Greek pará- and prifices solid could by their task namely without effort or cost a meal. own power but by means of organisms of a different kind. As a rule, of an term parasitic; usually a parasite is used in body fluids tissue or m	odel/explanation] d sitos it means, ne Parasitism is unde organisms become nutrients of the hos	xt to and fattened, ori erstood today the supp significantly larger th t as a source of food"	ginally so the tasters called oly of resources but not from oan the parasite of the	

10:10- 17:14	465 466 467 468 469 470 471 472 473 474 475 476 - 477 478 477 478 479 480 481 482 483 484 - 485 486 487 488 489 490 491 492 493	<ul> <li>Anne: Short question: tissue how is that related to the plum?</li> <li>Ellen:also eats the tissue, also takes out the liquid [water], so it destroys the tissue and after that the liquid of the fruit.</li> <li>Anne: Do we want to write something down about that?</li> <li>Hallie: somehow such a tree already, so everything happens.</li> <li>Anne: We just write that on an extra sheet.</li> <li>Ellen: And what do we want to write below? Because consumer 1 [the maggot] [3s] just gets the nutrients from the host</li> <li>Hallie: that will be classified again in the video. I would then just</li> <li>Anne: So what that one is [the maggot] [3s], with this model.</li> <li>Ellen: Yeah, that's what we'll write below [in the paper they start writing the explanation].</li> <li>Hallie: Do we write down that the parasite gets all from the host?</li> <li>Anne + Ellen: Yes.</li> <li>Hallie: Consumed liquids</li> <li>Anne: Then the tissue. Liquids are things like water, but glucose is something like that, isn't it?</li> <li>Ellen: Yes, also glucose. Nutrients in the tissue.</li> <li>Hallie: Nutrients. What did we say, what's in the nutrients?</li> <li>Anne: Vitamins, like B- and C-vitamins [looking at her individual representation] [2].</li> <li>Hallie: And we said something else earlier. Starch?</li> <li>Ellen: Yes, starch also!</li> <li>Anne: We forgot nitrogen</li> <li>Ellen: Doesn't get into?</li> <li>Anne: It remains relatively constant. We would probably have to read again. I'll do something like that now [Draws nitrogen around the maggot] [3y].</li> </ul>	Activities inside the plum and differences between substrate and products.	Attempt to articulate in the "explanation" ideas from the content in the video. Inputs (fungi and maggot boxes) and outputs (liquid from the fruit).	The written "expression" of the model. Using individual representations to support the creation of the group models.	E17 De- constructing the content from video to understand the transformation Analyze (decide) which aspects of the KI (from the video) are useful to understand the changes Content (consumer) and focus on what the fungi and maggot are causing to the plum. Flow of matter from fruit to fungi and maggot.
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# [12:30- 12:50]

Video: "Predatory-Parasites" also called parasitoid, this is a bit different in the fact that they kill their host after they have completed their				E18
development cycle in the hosts. Occurs through the parasites often a special disease and then speaks of parasitosis.				Analyzing facts
-	[12:50]	Concept	to	from the video
494	Hallie: It's not a parasitoid, it's a normal one, isn't it?	"describe"	the	wa ith focus on

495	Ellen: That's the question.	kind of relation		the "scientific"
496	Hallie: So it kills the plum?	the fungus and		terms (for
<b>497</b>	Anne: Yes.	the maggot		classifying
<b>498</b>	<b>Ellen:</b> I think yes, because the tree isn't killed, but the fruit. So both	have with the	Difference	fungus and
499	are parasitoid.	plum.	between the	maggot) rather
500	Hallie: [while writing] Consumer 1 [the maggot] and 2 [the	*	concept of	than in the
501	fungus], are parasitoid.		"parasite" and	interaction
502	Anne: Although, with the maggot inside you still can eat the		"parasitoid" in	fungi-plum that
503	plum		regard to the	is causing the
504	Hallie: If this happens independently, then yes. But now we start		organisms (TBs)	transformation
505	from the plum, which has both [maggot and fungus].		they have already	in the plum.
-	Anne: Are we going to write that now?		identified.	
-	Hallie: Yes, I would say.			
506	Anne: -you can explain that. Because at the latest, somebody says,			
507	if you eat maggot, -			
508	Hallie: So parasite 1 [the maggot] and 2 [the fungus] together are			Compare fungi
509	parasitoids.			with other
510	Anne: Yes, only in that combination.			"parasites" to
511	Hallie: [While writing] Destroying the host.			understand it
512	Anne: Well, only the fungus is also destroying. So just the maggot			role
513	isn't a parasitoid, but the fungus is.			(classification)
514	Ellen: Only the maggot alone is not a parasitoid			
515	Anne: But the fungus.			Is this attempt of
516	Ellen: Little parasite.			classifying the
[13:4	8- 14:15]			fungi and maggot
Video	<b>:</b> "The parasites are highly specialized in the host, for example with	their clamps or so	organs in people or leeches. The parasites	productive to
usual	ly have only a few host species, they are also specialized in only one	host, they are calle	d monoxenous in a few species are called	interaction of both
oligoz	xenous and polyxenous in many different host species"			— with the plum and
517	Ellen: Polyxenous, because are for different stone fruits and		Trying to classify	the central
-	[Hallie writes]		the fungus	transformation in
518	Anne: But that's not only polyxenous, they mean not only one		according to its	the fruit?
519	species, but		role. (Are the fungi	Somehow express
520	Ellen: Just one special thing, for instance, if it just occurs on		specific for the	the relation
521	Anne: Just on the plum.		plums?)	among them but
522	Ellen: So not poly- [polyxenous], otherwise they would encroach			does it have an
523	to other things, the fungus for example also on, no idea snails or			explanatory potential about
524	something			

525	Hallie: So not the second stage then?		how/why all of
526	Ellen: Yes, so oligoxenous		them are
527	Anne: Monoxenous would be just now.		changing?
[14:5	8- 15:07]		
Repla	ay the video part: "The parasites usually have only a few host species, they ar	e also specialized in only one host, they are called	
mono	exenous in a few species are called oligoxenous and polyxenous in many differe	ent host species".	
528	Ellen: So for example, head lice are monoxenous and they're only	Specificity in the	
529	dangerous for humans.	classification of	
530	Anne: But if you just got the human being and that's monoxenous,	the fungus and	
531	isn't the stone fruits also monoxenous, because it's stone fruits? Do	maggot.	
532	you know what I mean? [Hallie writes]		
533	Ellen: Yes	Use other	
534	Anne: Because the lice so if they're monoxenous, so just for	examples to	
535	one then they would only appear on European people or else.	understand this	
536	Hallie: But human is human.	classification.	
537	Anne: Yes, that's why it would have to be monoxenous, because		
538	Hallie: Jap, with the lice already.	Lice-humans	
539	Anne: So the maggots too. If they only appear on stone fruits or do	Maggots- apples	
540	they go		
541	Ellen: They also appear on apples.		
542	Hallie: But apples are non-stone fruit, aren't they?		
543	Ellen: They appear on many different fruits. Not every fruit, but		
544	many. The fungus is specific for stone fruits.		
545	Anne: The apples then have other infestations.		
546	Hallie: So the maggot is oligoxenous and the fungus is		
547	monoxenous?		
548	Anne + Ellen: Yes.		
549	Ellen: For P1 [the maggot] is that [oligoxenous].		
550	Hallie: Monoxenous one specie, isn't it?		
551	Ellen: Yes, the stone fruit.		
552	Anne: So the stone fruit as one specie?		

# [16:35-16:47]

[16:3	5- 16:47]		E19	
Video: "Parasites that possess only one host throughout development are called homoxenous. If at least one host changes during its				
development cycle, then this is called heteroxenous."				
555	Ellen: Homoxenous, both.	Maggot and	the video and the	
556	Hallie: Both parasites homoxenous, because only one host per	fungus depend on	model/explanation	

	557 558 559	Ellen: Life cycle. Anne: Then it fits perfect, because we can relate our problem with the video content [points the representation] [3]		the plum most of their life cycles.	(maggot and fungus depend on the plum to survive)		
	560	with the video content [points the representation] [5].					
Crown	500	2.50]			_		
3 Tool	U.UU Vide	• 2.30] • "For example, they have one host species as a larva and another as	a finished insect O	ne differentiates further different kinds of parasites			
2 2 4	mosa	uitoes or ticks for example live not within the host but only on top of	f it these parasites	are called Fro or outside parasites, they penetrate			
0.20-	only	nates of news, for example live not within the nosi, but only on top of partly into the organism of the host usually only with the organs served	e for supply They	feed on fluids tissues from the blood or on the skin			
9:27	Tapeworms or the maggats of the warble fly are endoparasites meaning they live inside the host. They can stay inside or outside the cells and						
, <b>.</b>	are called intra or extracellular						
	A dis	tinction is also made between facultative and obligate parasites. wh	hich do not need to	compulsively develop a host in order to develop			
	parasites only occasionally. The others are completely dependent on the host for their development. Temporary parasites such as mosauitoes						
	are n	to t permanent in their host, but visit him only for a certain time, for	example, to take for	ood. Parasites living permanently or in a host are			
	calle	d stationary.	1 / 5	01 2			
	Thev	can be divided into two further groups, they are periodic if they live	e only in certain st	ages of development parasitic egg only as larvae.			
	Perm	panent parasites spend their whole lives with their host, plants in whi	ch parasitic live ar	e called phytoparasites, some of them that are full			
	paras	sites completely dependent on their host."	1	I J I I J I I I J I I I J I I I J I I I J I I I I I J I	<b>.</b>		
	561	<b>Ellen:</b> The fungus. That's a problem right now.	Focus on the		- Attempt to use		
	562	Hallie: Is the fungus a phytoparasite?	relation fungus-	the "terms" of			
	563	<b>Ellen:</b> Becausethe parasites [maggot and fungus] are actually	plum	Plum allows the	the video to		
	564	not only in one state of development but in more than one state.	I	development of the	understand the		
	565	So the fungus has only 2, therefore it's just there as spores and		fungus. From	interaction		
	566	then it develops, gets bigger, and produces spores again.		spores to fungus.	(relation)		
	567	Anne: Right.	Relation	The developed	between		
	568	<b>Ellen:</b> But the fly has more development states. One here [points	maggot-plum	fungus can	maggot-plum		
	569	in the representation of the fly going out the plum [3v] and one		produce spores	and rungus-		
	570	here in the host in winter [in the tree] [3f] or in the egg lying [in		again to continue	plum		
	571	the plum] [3g]		its life cycle.			
	572	Anne: And in 2 stages, it [fly] is in there [plum]. In both of the		(Implicit)			
	573	states it is inside [points in the representation the egg [3u] and the					
	-	maggot [3s] inside].		Plum allows the			
	574	Ellen: So it's still		development of the			
	575	Anne: So half of their life it stays inside [3u] [3s].		maggot in some			
	576	Hallie: Then it's not stationarly-periodic, but stationary-		stages of their life.			
	577	temporary.		-			
	578	Ellen: Yes, that's what I'd say too.					
	579	·					

-	Anne: There was only temporary or stationary, right? [Looks		
580	again in the video]		
581	Ellen: But temporary is just a short term.		
582	Hallie: In the video, there were 3 forms.	Fungus stays in the	
583	<b>Ellen:</b> Yes, the stationary is distinguished. Whole life or	plum while it is	
584	Anne: Or while special states of development, which fits to our	enough food it	
585	parasites.	produces spores to	
586	Hallie: So which one is it then?	guarantee its	
-	Anne: Stationary wait. [Replays the video: "are only in certain	existence.	
587	stages of development - are we ves For example, only one as		
588	<i>larve</i> ] Permanent parasites we don't have.		
589	Ellen: They are in a stage at least outside		
590	Hallie: Yes that's right. So we have it right.		
	Anne: Okay.		
[5:08	- 5:20]		E20
Vide	: "They (parasitic plants) do not carry out their own photosynthesis	, but draw their entire energy from the host again pale yellow	As the video
sumn	er was unfortunately like to wash on crops".	,	progresses, the
591	<b>Hallie:</b> The fungus – to which group can we classify it?	Role of the	classification of
592	Anne: You mean, if it's a phytoparasite?	fungus and	the parasites
593	<b>Ellen:</b> Can we again see the explanation for phytoparasite?	maggot	becomes more
594	Anne: Could the fungus be	Classification	diverse. I think it
595	Hallie: A phytopparasite is related to plants.	of the fungus	helps them to
596	Anne: Or the fungus.		interpret the role
597	Hallie: Yes. right!		of fungus and
598	Anne: But the fungus couldn't survive on its own, because it		maggot in relation
599	needs		with the plum.
560	Hallie: But it will split up.		Maybe deepen in
[5:3			what do fungus
9- 5:4	181		and maggat are
Vide	: "The half-parasites such as the mistletoe fused with their host	and withdraw in the water and minerals, photosynthesis but they	taking from the
thems	elves"		plum. This might
561	<b>Ellen:</b> I think that the fungus does not need the photosynthesis.		be relevant for the
562	Maybe some of them. We can google it.		connections and
563	Anne: [while writing in the searcher] fungus photosynthesis		exchanges among
-	Hallie: What is the name of the fungus? Monila Write just		the boxes,
-	fungus.		identifying the
-			inpuis (from

	-	[5:55-7:38] Look for information in internet. Does fungus made		Regarding the	where) and the
	564	photosynthesis?		aspects of the KI	outputs of the
	565	Anne: But you know The spores are flying around and they		from the video.	boxes.
	566	find a host, there is an injured tree (plum).		Fungus and	
	567	Hallie: Do you think they [spores] live due to the photosynthesis		maggot depend on	
	568	in the plant?		the plum to get	
	569	Ellen: They need the nutrients.		nutrients.	
	570	Anne: Do they need photosynthesis? The fungus			
	571	Hallie: Does the fungus belong to the group of plants?		The fly is not	
	572	Anne: Nooo.		taking directly	
	573	Ellen: Fungi are something else.		nutrients from the	
	574	Anne: Because they didn't need the photosynthesis to like the		plum according to	
	575	mistletoe [example from the video]		their	
	576	Hallie: These are only plants.		phenomenological	
	577	Anne: They [fungus] only need the nutrients, in a general way.		context.	
	578	Hallie: So they are fully parasites.			
	579	Anne: Yes, I would say.			
	580	Ellen: But the fly doesn't?			
	581	Hallie: But wait! Those phyto [phytoparasite]no idea what, is			
	582	just related to plants, that means our parasites don't belong to this			
	583	group.			
	584	Anne: Ahh, you mean the fungus doesn't belong to the plants			
	585	Hallie: Yes, so we don't need the facts from the video			
	586	anymore.			
	587	Ellen: So it's just related to plants?			
	588	Hallie: In the video, he [the video narrator] said plants are			
	589	phyto [phytoparasites]			
	590	Anne: Yes, I already know what you mean [looks in the video]			
	591	Phytoparasites wouldn't fit, because none parasite we got, is a			
	592	plant			
	593	Hallie: Yes			
		Ellen: Yes, so we can leave it out.			
		Hallie: Do you see something else that could be important?			
		[9:14- 9:27] Play the video and decide they do not need it			
		anymore.			
Group	-	Anne: So we wanted to write here [in the representation they are	Return to the	The amount of	E21
3 Tool	594	constructing] [Looks in her representation (Figure 2) [2]] So we	change of the	sugar water that is	

2. 2.4. 9:30- 17:14	595 596 597 598 599 - 600 601 602 603 604 605 - - 606 607 608 609 610 611 612 613 614	<ul> <li>need the state, where the glucose [pointing in the representation [3]], so the liquid-stuff</li> <li>Ellen: Yes, this sugar water, which is very, very viscous.</li> <li>Hallie: Brown maybe for glucose. As drops.</li> <li>Anne: Yes, and relatively much. [Draws drops that represent the glucose going out the plum [3z]],</li> <li>Ellen: Therefore, we need another hole [in the surface of the plum],. These are the cracks, which develop, because the plant dries out and then there's liquids coming out.</li> <li>Anne: Right.</li> <li>Hallie: That's [plum] still a box [transformation box], right?</li> <li>Anne+ Ellen: Yes. [Anne draws a small square in the surface of the plum to emphasize the process there: exchange of water and sugar with the environment] [3z]</li> <li>Ellen: In the box goes in water andOr out. So water and glucose goes in.</li> <li>Hallie: Wait, isn't that glucose. Sugar?</li> <li>Ellen: That's mixed what goes out.</li> <li>Anne: Fructose plus glucose. And of course, it goes out [while writing] [3z], but much more.</li> <li>Ellen: So it's connected and there's much sugar and less That's viscous like syrup.</li> <li>Hallie: Like resin.</li> </ul>	plum (in the final states) Output of the plum: sugar water Plum as TB Water and glucose: input and output	<ul> <li>going out of the plum is bigger.</li> <li>Water is going in and out from the plum. However, the amount of water going out is bigger.</li> <li>S: water (the plum is in a constant exchange of water with the environment)</li> <li>C: the amount of water going out is bigger.</li> </ul>	Conceptualizing the transformation as differences between inputs and outputs (matter) Characterize differences between substrate and products or as differences between what gets in and what gets out of the boxes (plum).
	- 615 616 617 618 - 619 620 - 621 622 623	<ul> <li>[11:11]</li> <li>[11:17]</li> <li>Anne: We do not have the stage of development of the plum here, which is at the same time. So if it's still immature and if it ripens quickly then.</li> <li>Hallie: Like you constructed it in the model. So there [pointing on the left side of the representation where there is no fungi] is this state.</li> <li>Anne: Actually, we just need this state or we take like a section [which divides the two states of the plum unripe and ripe].</li> <li>Hallie: Yes, I'd do it this way, just a section here [pointing on the middle of the plum], when the fungus is affecting the fruit, the "juice" there is green.</li> </ul>	Change in the plum is associated with the presence of the fungi and maggot and the "natural" ripening process	S: ripening process C: accelerated by the presence of fungus and maggot in some parts of the plum.	E22 Conceptualizing the transformation as the flow of matter, energy, and information among boxes/organisms Explain the change, according to what each box

624 625 626	Ellen: The juice which dries out Hallie: That's still the green on the top, then follows some violet and then brown. [Anne paints and Ellen writes in the legend of		Plum provides protection and	does and the connections between them.
- 627 628 629 630	the representation]. <b>Anne:</b> So the brown part is the fungus So do we want to begin again with the fly and the egg, that's what we already got It [maggot] also has got protection against predators and it develops. [Writes "protection against predators" inside the square they use to emphasize the maggot as a TB [3s]].		food for the egg.	Build causal chains that explain the flux of matter (water), energy
631 - 632 633 634 635 636	<ul> <li>Ellen: Also protection against the weather! [Anne writes] [3s]</li> <li>Anne: That's what we learned in the lecture. That they build their environment.</li> <li>Ellen: That's like a bunker, in which it gets everything which is necessary.</li> <li>Anne: Right, so it's its protection cover and food. So we can sum it up as food. [Writes "food" referring to carbon dioxide [3o], oxygen [3m], water [3n], nutrients [3q]]. Food and protection.</li> </ul>			(stored in the sugar?) and information (that calls the fly) among boxes and with the environment.
637 638 - - -	<ul> <li>[13:50]</li> <li>[Anne draws more dots as feces of the maggot [3t] and writes "<i>feces</i>"]</li> <li>Hallie: No, these here [the dots that represent the waste products of the fungus [3r]] are from the spores.</li> </ul>			<b>E23</b> Differentiating transformations through their dimensions
639 640 641 642 643 644 645 - - 646 647 648	<ul> <li>Anne: Ahhh yes, here feces [of the maggot [3t]] and how is it call? [the wastes product of the fungus [3r]]</li> <li>Ellen: Waste products. That was our question.</li> <li>Hallie: I don't know. What kind of waste matter does the spores/fungi got?</li> <li>[14:13- 16:00] They search on the internet for the products of the fungus. Source: Google books.</li> <li>Anne: The fungus produces the glucose from the starch. The plum has a lot of starch.</li> <li>Ellen: It [fungus] uses glucose to live, as energy.</li> <li>Anne: And it produces by itself [glucose]. I thought it was the plum.</li> </ul>	Output of the fungus: glucose	The waste products of the maggot are different from the fungus. The changes inside the TBs-maggot and TBs-fungus	Differentiate the transformation in the maggot and fungus as the products are different even they have the same inputs from the plum (similar relation)
649 650	Hallie: So the fungus produces glucose. Anne + Julia K: Yes		are different, although they are	

	651 652 653 654 655 656	<ul> <li>Hallie: But feed it [glucose] the fungus overall.</li> <li>Anne: [while writing as an output of the fungus] So glucose. That is why there is also less water [inside the plum]</li> <li>Hallie: Here [pointing the spores] starch goes in.</li> <li>Ellen: We have no written starch.</li> <li>[Anne draws crosses to represent the starch going in the TB spores [3a']]</li> </ul>		receiving the "same" inputs from the plum. Input of the fungus: starch and water Output: glucose		
Group	657	Anne: We have a lot of starch, right here up [in the upper part of	Inside the		E24	
3.	-	the plum] [3a']	plum: starch		Conceptu	ualizing
Tool	658	Hallie: Exactly			the transi	formation
2. 2.5.	659	<b>Ellen:</b> If it [plum] is still fresh.	Initial state of		on unrei	ent levels
0:00-	660	Anne: Before ripening. Exactly	the plum	Referring to the	Differer	ntiate
2:12	661	Hallie: Exactly and then you can draw a drop like glucose here		processes inside	visible a	and
	662 663	[pointing the spores-1B] [5p]		the plum as part of	invisible	e
	005 664	Hallie: Hara so [as an output of the spores TP] [2b'] when the		ripoping:	changes	5
	665	ducose is produced from the starch		production of	(Invisib	le: starch
	666	Anne. Ves		sugar from starch	$\rightarrow$ sugar	r)
	667	<b>Ellen:</b> Here there are still such a small drops		sugar moni staron.	(Visible	e: color,
	668	Anne: [While drawing [3b']] Like that			shape,	
	669	Ellen: Wonderful [nodding]			consiste	ency)
	670	Anne: Ok	Substances			
	671	<b>Ellen:</b> So $O_2$ we had here [as an output of the plum] [3m], what	produced by			
	672	else? Tannins	the plum:			
	673	Hallie: They [tannins] are then most likely to be found in the	oxygen, tannins		Describe	e these
	674	lower part [where the plum is ripe].			changes	s inside,
	-	Anne: What I am doing now. [Paints] [3c']		Oxygen and	outside	and at
	-	Hallie: Is there still pink?		tannins are also	the surfa	ace of
	675	Anne: [While continuing painting [3c']] Definitely, yes it is		products of the	the boxe	es.
	676	definitely a waste product. Tannins that definitely the plum		plum. Those are		
	677	develops So, yes in the lecture, it was almost on how it		part of the ripening		
	678	changes, that you look, how the color changes, the shape, the		process (inside the		
	679	consistency, here it would be the starch content and these		plum). This		
	680 (01	individual stages [of the change]. We have them now.		process implies a		
	081 (82	<b>Hame:</b> we can visualize this by picking up the plums,		change in color,		
	682 682	A new So when it's the sesson		snape, and		
	683	Anne: So when it's the season		consistency.		

- Anne: They [tannins] are suspended. 685
- Hallie: They are suspended and then we pick up two out so we 686
- leave one in so that the green remains. 687
- 688 Anne: Maybe within four weeks.
- Hallie: Exactly and if they're in the purple color stage then 689
- tannins are suspended and then wait with the other until they're 690
- really tanned [Ellen nods] 691
- Ellen: Maybe we have to do that first. 692
- 693 Anne: Yes
- **Ellen:** I would say that too 694
- Anne: And then stays in the tanned state. And then I look, I do 695
- 696 not know if you also have sources [where to pick plums up]? So I
- definitely have maggots [Hallie laughs] But I think our trees do 697 not have fungus, although I've seen that before, in this picture. [2:12-7:52] Different topic. The possibility to make an experiment with plum and maggot. Talk about some extra information about fungi. Reading the tool



Figure 3. Final explanatory model articulates the aspects of the key ideas from the video

They are relating the changes in the micro-level with the "manifestation" of these changes in the macro-level (the production of sugar, water, and tannins are perceived as changes in the color, consistency...)

to

the

"both

Somehow in the representation, they aimed illustrate changes" Refer to some ripening process materiality to (one part of the be sure about plum is green and the observable the other is purple) aspects of the and in the ripening part, the change is due to the presence of the fungus and

maggot.

change.

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# 9.4 Appendix D. Second Iterative Cycle's Pedagogical Tools

## 9.4.1 Pedagogical tool 1

### Unterstützendes Tool 1: "Changes im Phänomen wahrnehmen und dabei Aspekte von Stability entdecken"

Ziel: Beginnen Sie ein Naturphänomen, durch die Charakterisierung von Veränderungen und den zugehörigen Stabilitäten, zu untersuchen. (Stability und Change)

# Teil I: Identifikation und Charakterisierung von Changes in Naturphänomenen

1. Identifizieren Sie die Changes, von denen Sie denken, dass sie sichtbar, wahrnehmbar oder vorstellbar bei einem Naturphänomen sind. Orientieren Sie sich bei der Darstellung der Changes an den unten abgebildeten Figuren der Tabelle 1. Beachten Sie zur Charakterisierung der Changes die Aspekte a) bis e) im eingerahmten Kasten.

Aspekte, die Sie zur Charakterisierung der Changes in Tabelle 1 beachten sollten:

- a) Was sind Anfangs- und Endsituation dieses Change-Aspektes? Gibt es Produkte der Change, die zuvor nicht da waren? Was denken Sie sind Inputs (linker Pfeil) und Outputs/Ergebnisse (rechter Pfeil)
   Co-constructing changes through its three biological/epistemological dimensions: matter, information and energy.
- *b)* Changes können unter extremen Bedingungen stattfinden. Wie sehen die Changes aus, wenn sich die Voraussetzungen im Laufe der Zeit verändern?

Co-constructing the change through magnitude (quantity).

 c) Changes können auf verschiedenen Ebenen stattfinden, die sichtbar oder unsichtbar sein können. Übertreiben und untertreiben: bedenken Sie auch sehr große und sehr kleine Bedingungen. Welche changes können (nicht) gesehen werden? Wie stellen Sie sich die unsichtbaren Changes vor?
 Co-constructing the change through its levels.

- *d)* Changes können in unterschiedlicher Geschwindigkeit geschehen. Welche können Sie identifizieren? Laufen sie schnell oder langsam ab?
- Co-constructing the change through magnitude (speed).
- *e*) Changes können an bestimmten Orten, zu bestimmten Zeitpunkten oder in einem Abstand zueinander stattfinden. Welche Changes geschehen gleichzeitig? Welche nur zu unterschiedlichen Zeiten?
   *Co-constructing changes through space (place, distance and time).*



#### Teil II: Aufstellen von gegensätzlichen Paaren (Stability und Change ) und Evaluation ihrer Relevanz

2. Benennen Sie alle Aspekte von Change nach ihrer Aufgabe im Prozess. Listen Sie diese in der Tabelle 2 auf. Identifizieren Sie für jede Change etwas, das trotz der Veränderung gleichbleibt. Das ist Ihr erster Versuch Stability und Change als Gegensätze gegenüberzustellen. Um über das Phänomen hinaus weitere Aspekte der Kernidee(KI) zu erkunden, sortieren Sie die Paare nach der Größe ihres Einflusses auf den Prozess.

*Co-examining the relevance of the antinomies for the aspects of the biology core idea (s)* 

Tabelle 2. Paare von Veränderungen-Stabilitäten-Gegensätze und ihre Relevanz für das Naturphänomen

change	stability	Relevanz für das Verstehen des Phänomens in Bezug auf die Kernidee
1.	1.	1.
2.	2.	2
3.	3.	3.
	·	•

**3.** Nutzen Sie die Tabelle 2, um eine Leitfrage zu formulieren, die Ihre modellbasierte Untersuchung stützt. Es muss eine "Wie-Frage" sein, die ein übergeordnetes Problem beinhaltet, des Naturphänomens beinhaltet, an dem Sie arbeiten. Das Problem muss aus Aspekten von Stability und Change bestehen, die eventuell noch nicht in Ihrer Tabelle stehen, aber mehrere Aspekte der Tabelle zusammenhängend umfasst oder berücksichtigt.

## 9.4.2 Pedagogical tool 2

# Unterstützendes Tool 2: "Modellierung mit TBs, um stability und hange zu verstehen und zu ordnen."

Ziel: Charakterisieren der "Changes and Stabilities" Eigenschaften des Phänomens als Transformationen und die Organisation in TBs, um die Aspekte der Kernidee umzusetzen und zu koordinieren.

Teil I: Changes/Stabilities als biologische Transformationen verstehen			
1.	Sehen Sie sich das/die inhalts-basierende/n Video/s an.		
2.	Nutzen Sie die die Aspekte der biologischen Kernidee aus dem/n Video/s zur Verbesserung der in Tool 1		
	identifizierten Veränderungen. Figur 1 kann dabei hilfreich sein.		
De-con	structing scientific content knowledge from videos through its relation with the natural phenomenon –		
change	s and stabilities-		
3.	Charakterisieren sie die Dimensionen von Materie, Energie und/oder Information, welche auf die Pfeile als		
In- oder Output für die TBs geschrieben werden können. Die Aspekte des unteren Kastens sind dafür			
hilfreich:			
Examining "changes and stabilities" through the biological-epistemological dimensions before and after the			
biologi	cal transformation takes place		
	Dimensionen den Changes" die ale Décile demostelltwonden		

The second second second	
Transformation	
т	
Concerned -	

Figur 1. Allgemeine Darstellung einer Transformationsbox. Die Pfeile repräsentieren die Dimension von Materie, Energie und/oder Information.

# Dimensionen der "Changes", die als Pfeile dargestellt werden können:

- f) Changes in der Materien vor und nach der Transformation
- *g*) Welcher Aspekt bewirkt die Veränderung der Materie und verändert sich der Aspekt dabei?
- *h*) Was fungiert als Signal, welches die Veränderung beginnen, anhalten, beschleunigen oder verlangsamen lässt? Welches Signal wird anschließend von der Box ausgesendet?

#### Teil II: Konstruktion von erklärenden Modellen mit Hilfe von TBs

- 4. Schauen Sie sich die Videos mit Fachinhalten erneut an. Achten Sie besonders darauf, was dafür relevant ist, Ihr Phänomen besser zu verstehen, beispielsweise die Teile des Videos, die Hinweise über die Organisation der Boxen innerhalb des Modells liefern.
- 5. Kommen Sie nun auf die in Tool 1 entwickelte Leitfrage (LF) zurück. Sie sollen ein erklärendes Modell konstruieren, welches diese Frage beantwortet. Um das zu erreichen, werden Sie die Transformationsboxen so miteinander verknüpfen, dass ein starkes Modell entsteht. Dazu können Sie erneut das Video anschauen, um sich dann zu entscheiden, wie die Boxen zusammengesetzt werden sollen. Die Figur 2 ist ein abstraktes Beispiel von TBs, die gerade zu einem Modell verknüpft werden. Die im Kasten aufgelisteten Aspekte helfen Ihnen, bei der Bewältigung der Aufgabe.

Developing organized forms (models) of phenomena (changes-stabilities) through the epistemic support transformation boxes and aspects from video by discussing mechanistic aspects such as observable and unobservable biological transformations, relevant biological structures with functions, dynamic fluxes of matter, energy, and information among TBs and the causes and effect of those dynamic fluxes.



#### 9.4.3 Pedagogical tool 3

#### Unterstützendes Tool 3: "Unterstützung des Entwicklung von modellbasierten Untersuchungen"

Ziel: Entwicklung von modellbasierten Untersuchungen anhand eines stärkeren TBS-Modells (Repräsentation und verschriftlichte Erklärung)

#### Teil I: Teilfragen entwickeln, um die Leitfrage zu beantworten

1. Entwickeln Sie eine Sequenz aus Teilfragen, die Ihnen helfen eine zusammenhängende Erklärung zu entwickeln. Jede der Frage wird durch Teile des Modells und der Erklärungen beantwortet.

2. Nutzen Sie die zugrundeliegende Kernidee bei der Entwicklung und Einordnung der Teilfragen. Alle Teilfragen zusammen sollen die Leitfrage beantworten.

Co-articulating changes-stabilities or aspects of the biology core idea (s) that can be modeled-explained better separately.

Nr.	Teilfragen	Aspekt der KI, welcher der Konstruktion eines Teilmodells/-erklärung zugrunde liegt		
1				
2				
3				
4				
Teil II: Erklärungen der Teil-TBs-Modelle mit allen Asnekten der KI				

3. Sie haben nun einige Fragen gesammelt. Betrachten Sie jede einzeln und entscheiden Sie, wie die finale Erklärung aus Tool 2 unterteilt wird. Figur 1 ist eine abstrakte Darstellung, wie Ihr Modell aussehen könnte. Nutzen Sie die Darstellung und die Aspekte aus dem Kasten, um Ihr eigenes Modell in 3-4 Teilfragen/-modelle zu unterteilen. Jedes Teilmodell soll eine Teilfrage beantworten.



Figur 1. Abstrakte Darstellung der finalen Modell-Erklärung

4. Vervollständigen Sie kurze, auf das Teilmodell zugeschnittene, Sätze, die das Phänomen grundsätzlich erklären.

#### Aspekte, die Sie beim "Zerteilen" des Modells beachten sollten:

a) Identifizieren Sie erneut die Haupttransformationen, die in Ihrer Modell-Erklärung dargestellt werden. Welche dieser Transformationen verbessert das Modell? Können Sie Fortschritte in der Erklärung durch die Verbindungen/Austausche zwischen den Boxen, Produkten der Boxen, Inputs der Boxen und/oder dem Gesamtfluss zwischen den Boxen, darstellen?

De- constructing the final model/explanation based on the aspects of the TBs: a) the dimensions of the change: matter, information, energy, b) connection or exchanges among the boxes (flow), c) connection or exchanges of the boxes with the environment, d) structure and/or function.

b) Nutzen Sie die Inhalte der Videos,, um Ihre Unterteilung des Modells zu überdenken. Kontrollieren Sie erneut die Aspekte der KI, die Sie in Ihrem Modell zugrunde liegen. Welche Aspekte der KI unterstützen die modellbasierte Erklärung?

*De-constructing the final model/explanation attending to the aspects of the biology core idea (s).* 

Notiz: Sie haben alle drei unterstützenden Tools abgeschlossen. Jetzt sind Sie bereit die Tabelle für die zentrale Übung 1 zu vervollständigen. Nutzen Sie alles, was Sie bisher gelernt haben, um die Tabelle auszufüllen und bringen Sie diese am Tag der Präsentation mit.

Data	<b>Event/Episodes</b>	Research Notes	
Dana   <u>studip</u>   24. Jun 2019, 12:23 <u>Beantwortung zu Tabelle 1 Teil a</u>	Defining phenomenon	• They start working in the <i>Forum</i> related to the first pedagogy, following the thread:	
a) Change: Anzahl der Mücken -> Beginn: wenig Mücken; Ende: viele Mücken -> Input: äußere Umstände; Output: erhöhter Anteil Mücken an einem Ort Change: Tageszeit -> Beginn: tagsüber: Ende: wird dunkel	Characterizing initial and final situations of changes	"Identifying and characterizing changes in natural phenomena."	
<ul> <li>Change: Ort</li> <li>-&gt; Beginn: Wiese; Ende: See</li> <li>Change: verschiedene Kinder</li> <li>&gt; Beginn: Kinder sind unterschiedlich, Ender unterschiedlich viele Mückenstiche</li> </ul>		• They tried to discuss all the proposed prompts:	
<ul> <li>-&gt; Beginn: Kinder sind unterschiedlich, Ende: unterschiedlich viele Muckenstiche</li> <li>Change: Mückenspray</li> <li>-&gt; Beginn: ohne Mückenspray; Ende: mit Mückenspray (neue Substanz kommt hinzu)</li> <li>-&gt; Input: Mückenspray; Output: weniger Stiche</li> </ul>		<ul><li>(a) Initial and final situations</li><li>(b) Extreme conditions</li></ul>	
Dana   <u>studip</u>   24. Jun 2019, 12:29	Characterizing	(c) Different	
Beantwortung zu Tabelle 1 Teil b	changes under extreme	levels (observable and unobservable)	
	conditions	(d) Different speed rates	
<ul> <li>-капп sein, dass die Muckenanzahl nicht zunimmt oder Konstant noch bleibt</li> <li>-Kinder können sich im Laufe der Zeit ändern -&gt; Ort bleibt gleich aber verschiedene Menschen, auf die die Mücken reagieren -&gt; unterschiedlich oft gestochen</li> <li>-Mückenspray erneuern -&gt; wird nicht gestochen über einen langen Zeitraum; verschiedene Sorten von Mückenspray -&gt; Auswirkung auf Anzahl der Stiche</li> </ul>		(e) Different times, places, or at a certain distance.	

# 9.5 Appendix E. Example of data collected in the Multimedia-Tools and event map

Marie   <u>studip</u>   24. Jun 2019, 12:36	Characterizing changes:	• They participate synchronously in the
Beantwortung Tool 1		Forum. It seems that many of the ideas
Anfangssituation Kind ohne Mückenstich —> Endsituation Kind wurde von Mücke gestoch (Mückenstiche) Einfluss unterschiedlicher Faktoren beeinflusst Anzahl der Mückenstiche	nen (a) initial and final situations	they have been exchanging during the face-to-face
Changes unter Finflüssen.		lectures and
Tageszeit Nacht/Abend —> mehr Mückenstiche Ort (See) —> mehr Mückenstiche		seminars were shared via Forum.
Verwendung von Mückenspray —> weniger Mückenstiche Individuelles Kind (Blutgruppe, Körpergeruch und Temperatur, Kleidung) —> individuelle an Mückenstichen	e Anzahl (b) extreme conditions	Compared with the
Temperatur —> Sommer —> mehr Mücken		other groups
Unsichtbare changes: Blutgruppe von Kind bzw. individuelle Eigenschaften, Mückenspray sichtbar)	(nicht (c) different levels	analyzed so far, this group makes an effort to characterize
Sichtbare changes: Tageszeit, Ort, Muckenspray (riechen), Temperatur?, Kleidung vom K	(observable and unobservable)	the changes and
Schnelle/Langsame Changes: Schnell:Mückenspray, Ortwochsel2	(d) different	stabilities in detail. I
Langsam: Tageszeit, Temperatur (generell auf Sommer bezogen)	(d) different speed rates (fast	productive for the
Nicht änderbar: Kind (Eigenschaften)	and slow)	whole planning
Dana   <u>studip</u>   24. Jun 2019, 12:37	Characterizing observable and	<i>- practice. For example, that they do not lose track of</i>
<u>Beantwortung zu Tabelle Teil c</u>	changes	the stabilities when
<ul> <li>c) -sichtbar: Tageszeit, Ort, verschiedene Kinder, Kleidung, Anzahl der Mücken</li> <li>-unsichtbar: Eigenschaften des Blutes, Temperatur, Mückenspray</li> <li>- Vorstellung der unsichtbaren Changes: unterschiedliche Blutgruppe -&gt; verschiedene Te</li> <li>Temperatur -&gt; Energie der Teilchen; Mückenspray -&gt; Schicht auf Haut, die CO2 Ausstoß</li> <li>Haut verbindert (und Geruch überdeckt2)</li> </ul>	eilchen; über die	developing the explanatory model (second pedagogy) and designing the instructional
-unsichtbar: Eigenschaften des Blutes, Temperatur, Muckenspray - Vorstellung der unsichtbaren Changes: unterschiedliche Blutgruppe -> verschiedene Te Temperatur -> Energie der Teilchen; Mückenspray -> Schicht auf Haut, die CO2 Ausstoß Haut verhindert (und Geruch überdeckt?)	eilchen; über die	(second pedagogy, and designing the instructional

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Dana   <u>studip</u>   24. Jun 2019, 12:40	Characterizing changes at	sequence (third pedagogy).
Beantwortung zu Tabelle 1 Teil d	different speed rates	• They created an initial model that represent the group's shared ideas (Figure 1). It summarizes the main TBs the group start identifying and
d) schnell: Mückenspray, Ort, Kleidung langsam: Tageszeit, Anzahl der Mücken?, Temperatur neutral: Kind		
Natalie   <u>studip</u>   24. Jun 2019, 12:47		the change-stabilities features to focus on
Beantwortung Tool 1	Characterizing	in the model/explanation.
	situations of	
-Anfangssituation: Kind hat keine Muckenstiche	changes	
-Endsituation: Kind hat mind. einen Mückenstich		
> verschiede Faktoren beeinflussen dies: Tageszeit, Anzahl der Mücken, Ort, Verwenung von Mückenspray, Blut der Kinder		
b)		
-bei Veränderung des Ortes (näher an See), der Tageszeit (am Abend), Anzahl der Kinder (große Gruppe) und bei keiner Verwendung von Mückenspray ist das Risiko von Mücken gestochen zu werden höher	Characterizing under extreme	
-außerdem: abhängig vom Kind	conditions	
-Veränderung des Ortes:		
See: hohes Risiko gestochen zu werden		
Wiese: geringes Risiko gestochen zu werden		

-Veränderung der Tageszeit: Tagsüber: geringes Risiko gestochen zu werden Abends: hohes Risiko gestochen zu werden

-Individualität der Kinder:

Blutgruppenabhänig (Erklärung folgt später), Geruch, Temperatur, lange/ kurze Kleidung

-Verwendung von Mückenspray:

Einsatz von Mückenspray: geringes Risiko gestochen zu werden

kein Einsatz von Mückenspray: hohes Risiko gestochen zu werden

-Temperatur

hohe Temperatur = viele Mücken: hohes Risiko gestochen zu werden niedrige Temperatur = wenige Mücken: geringes Risiko gestochen zu werden

Schlussfolgerung: bei Veränderung der Faktoren verändert sich das Risiko gestochen zu werden

c)

-extreme Bedingungen (übertrieben und untertrieben schon in b) zu finden)

-Sichtbare Changes: Tageszeit, Ort, Mückenspray (riechen und sehen), Temperatur -unsichtbare Changes: Eigenschaften des Blutes der Kinder, Mückenspray (Funktionsweise)

Characterizing changes under extreme conditions

d) + schneller Ablauf - langer Ablauf 0 neutraler Ablauf Characterizing under extreme conditions

Temperaturwechsel (Bezug auf die Jahresezeit Sommer): - Ortswechsel: + Wechsel der Tageszeit: - Anwendung von Mückenspray: + Individualtität des Kindes Blutgruppe, Körpergeruch & -temperatur): 0	Characterizing changes at different speed rates
e) Welche Changes geschehen gleichteitig? -Temperatur- und Tageszeitwechsel -Temperatur-, Orts- und Tageszeitwechsel in Bezug auf die Anwendung von Mückenspray (auf Grund des hohen Risikos) -Temperatur-, Orts- und Tageszeitwechsel in Bezug auf die Anzahl der Mücken -Veränderung des Körpergeruchs und Tageszeitwechsel	Characterizing changes at different times
Welche Changes finden zu unterschiedlichen Zeiten statt? -Orts- und Tageszeitwechsel	
Dana   <u>studip_</u>   24. Jun 2019, 12:48	Characterizing
Beantwortung zu Tabelle 1 Teil e	changes at different times and places
a) gleichzeitig: Tageszeit -> Anzahl der Mücken -> Temperatur, Mückenspray -> Eigenschaften	

e) gleichzeitig: Tageszeit -> Anzahl der Mücken -> Temperatur, Mückenspray -> Eigenschaften der Haut, Ort -> Anzahl der Mücken unterschiedlich: Ort -> Tageszeit

Marie | <u>studip</u> | 24. Jun 2019, 12:48

#### **Beantwortung Tool 1 Teil 2**

Gleichzeitig/unterschiedliche changes:

Unterschiedlich: Ort, Tageszeit Gleichzeitig: Ort, Mückenanzahl; Benutzung Mückenspray abhängig von Tageszeit, Ort und Temperatur (Jahreszeiten), Körpergeruch abhängig von Tageszeit

Johanna   <u>studip</u>   24. Jun 2019, 12:48	Characterizing changes:		
Beantwortung Tool 1			
a) Anfangssituation: Das Kind hat keinen Mückenstich. Endsituation: Das Kind hat einen Mückenstich.	(a) initial and final situations		
b) extreme Bedingungen setzen bei Änderung der Tageszeit, des Ortes und Nutzung von Mückenspray ein. Weiterhin lassen sich Unterschiede bezüglich der Kinder feststellen und der Anzahl der Kinder.	(b) extreme conditions		
Tageszeit: Die Kinder werden am Tag häufiger gestochen als am Abend oder in der Nacht.			
Ort: Die Kinder werden am See häufiger gestochen als auf der Wiese.			
Mückenspray: Die Kinder werden bei Nutzung von Mückenspray weniger gestochen.			
Anzahl der Kinder: Die Kinder werden in größeren Gruppen häufiger gestochen als allein. Wenn sich die Bedingungen ändern, ändert sich das Risiko gestochen zu werden.			
c) -Bedingungen unter b)	(c) different levels		
<ul> <li>sichtbar: Tageszeit, Ort, Kleidung der Kinder</li> <li>unsichtbar: Blutgruppe der Kinder, Mückenspray, Temperatur, Körpergeruch</li> </ul>	(observable and unobservable)		
d) langsam: Temperaturwechsel schnell: Ortswechsel, Nutzung von Mückenspray neutral: Körpergeruch, Blutgruppe des Kindes	(d) different speed rates (fast		
e) gleichzeitig: Temperatur und Tageszeit	and slow)		

Der Ort und die Tageszeit beeinflussen die Nutzung von Mückenspray und können gleichzeitig ablaufen Ort und Anzahl der Mücken unterschiedlich: Ort und Tageszeit Körpergeruch und Tageszeit (e) different times and places

Gina | <u>studip</u> | 24. Jun 2019, 12:48

#### **Beantwortung Tool1**

a)Anfangssituation: Kind nicht gestochen/ ohne Mückenstich -> Endsituation: Kind wurde gestochen

b) Risiko gestochen zu werden ist erhöht, je nach Tageszeit (am Abend), Aufenthaltsort (vermehrt am See) keine Verwendung von Mückenspray, je nach Individualität des Kindes (Blutgruppe/Geruch/Körpertemperatur/Kleidung betreffend) und der Temperatur der Umgebung (hoch-> Sommermonate)

c) unsichtbare Changes: Blutgruppe, Mückenspray, Temperaturen Sichtbare Changes: Ort -> See, Tageszeit -> Abends, Mückenspray (wahrnehmbar durch Geruch)

d)schnell: Ortswechsel, Verwendung/ Auftragen von Mückenspray Langsam: Tageszeit, Temperaturwechsel (Sommermonate, relativ konstant warm) Neutral: Individualität des Kindes

e)gleichzeitig: Tageszeit und Ortsabhängigkeit in Bezug auf Mückenspray (an kalten Tagen keine Verwendung; an heißen Tagen am See gesteigerte Verwendung), Ort und Anzahl der Mücken unterschiedliche Zeiten:

Natalie | studip | 24. Jun 2019, 13:33

Defining the phenomenon

#### Modell Tool 1

erstellt von allen

Figure 1. Initial model that represents shared ideas regarding changes-stabilities

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			Constructing	Each group
<u>Changes</u>	<u>Stability</u>	Relevanz für das Verstehen des Phänomens in Bezug auf die Kernidee	opposites (changes- stabilities) and	contributes one row of the <i>Data</i> <i>Collection Table</i> . Each identifies a change with its corresponding
Mückenspray	Kind bleibt Kind	kein/ wenig Mückenspray: viel Mückenstiche, viel Mückenspray: wenige Mückenstiche	evaluating their relevance	
				stability and provides some

Tageszeit	Kind, Ort, Mücke	Je nach Tageszeit variiert Mückenanzahl und vergrößert sich Mückenstichanzahl. Am Abend ist Temperatur geringer, weshalb Mücken (nachtaktiv) vermehrt auftauchen.		Characterizin stabilities related changes	ng to	reasons regarding their relevance for examining the phenomenon.			
Ort,Anzahl an Mücken	Kind bleibt Kind	Feuchtigkeitsreiche Gebiete, wie ein See weisen eine größere Anzahl an Mücken auf. In feuchtigkeitsarmen Gebieten, wie Feldern, lassen sich weniger Mücken finden.							
Anzahl der Mücken	See	Morgen/Abend mehr Mücken, Mittag/Nachmittag weniger Mücken							
unterschiedliche Kinder	Kind bleibt Kind, Ort	mehr bzw. weniger Mückenstiche aufgrund unterschiedlicher Blutgruppen/ Körpergeruch							

Leitfrage: Wie kann es sein, dass unterschiedliche externe/ interne Faktoren wie die Tageszeit, die Blutgruppe (Mensch an sich) oder das Benutzen von Mückenspray verschiedene Auswirkungen auf das Stechen von Mücken haben, obwohl der Ort immer gleichbleibt? !!!!von allen formuliert!!!!	Formulating a driving question	They only wrote the driving question on the <i>Etherpad</i> . There was no discussion on selecting the key change-stability that guides the modeling- based investigation
Video 1: <u>https://www1.wdr.de/mediathek/video/sendungen/quarks-und-co/video-aus-dem-leben-einer-muecke-102.html</u> Video 2: <u>https://www.youtube.com/watch?v=uagBeKYBBvI&amp;t=1s</u>	De- constructing	• They start working on the activities corresponding to the

Johanna [studip_] - 27. Jun 2019	biology core ideas	secon devel	d pedagogy: oping the
Mücken stechen, weil sie durch die Blutaufnahme Eisen und Eiweiß erhalten, die sie selbst nicht produzieren können. - brauchen dies um Eier bilden zu können	Characterizing	expla via T online video	natory model Bs and using e content s.
Information: Mensch: Juckreiz/ Mückenstich, Mücke: Schweiß, Fettsäuren Energie erhalten sie durch die Nahrung (Blut) Materie: Blut (Eiweiß, Eisen)	TBs their epistemic dimensions	• The comm Blog	y add tents in the regarding the
Dana [studip_] - 27. Jun 2019		two p	rovided videos.
Materie: Blut -> Wie wandeln Mücken das Blut um? Was kommt raus? Was behalten sie in sich? Signal: Körpergeruch/ CO2 -> Was gibt Mücke an Menschen ab? Wodurch entsteht die Schwellung und der Juckreiz?		There signif	was a icant emphasis
Drößler, Natalie [studip_] - 27. Jun 2019		biolog	gical structures
Materie: Blut (Körperflüssigkeiten), Eiweiße und Eisen Energie: durch Nahrung Information: Juckreiz/ Mückenstich auf der Haut	(TBs) where the biological transformations take		
>Output: Reaktion auf die Haut, dazu gehören: Juckreiz, Schwellungen, der Mückenstich an sich (Quaddel)	place and on characterizing the three epistemic		
Signal für Mücken: Blut, Körpergeruch		dimer	nsions of each
Gina [studip_] - 27. Jun 2019		I DS	
Materie: Körperflüssigkeiten (Blut), Eiweiß und Eisen		(a)	Matter,
Energie: durch Nahrung Information: luckreiz/ Mückenstich		(b)	Energy
		(c)	Information.
Output: Muckensticn, Juckreiz, Ausschlagartige Ernebung/ Schweilung auf der Haut			
Marie [studip_] - 27. Jun 2019			
Materie: Blut (Körperflüssigkeiten), Eiweiß und Eisen			

Energie: durch Nahrung Information: Juckreiz, Mückenstich

Output: Mückenstich, Juckreiz, Schwellung/Quaddel auf Haut

Signal für Mücken: Körpergeruch

Natalie | <u>studip</u> | 02. Jul 2019, 23:06 Edited on: 02. Jul 2019, 23:11 - by Natalie | <u>studip</u>

#### **Gesamtmodell**

Figure 2. Group's mechanistic explanatory model of their plum phenomenon



Using the There is no further model to discussion in the *Forum* about the communicate a shared biology core idea and the use of the interpretation of the TBs tool for phenomenon interpreting biological transformations in their phenomenon. One participant uploaded the developed explanatory model (Figure 2). Although the model communicates the group's shared ideas that manifest meaningful relationships, it is still implicit how they come to those shared ideas.

Mücken stechen aus verschiedenen Gründen. Jeder Mensch sendet unterschiedliche Informationen an die Mücke, welche sie mehr oder weniger stark aufnimmt und somit einen Stechdrang aufbaut. Dazu zählen der Kohlenstoffdioxidgehalt, den der Mensch beider Atmung abgibt, den die Mücke über mehrere Meter hinweg wahrnimmt und somit den Standort des Menschen ermitteln kann. Darüber hinaus nehmen die Mücken die Fettsäuren und den produzierten Körpergeruch, den der Mensch in Form von Schweiß abgibt, wahr und reagieren daraufhin. Dieser Reiz liegt dem Drang nach Vermehrung zu Grunde, um die Ernährung der Brut gewährleisten zu können. Somit lässt sich zeigen, dass lediglich die weiblichen Mücken den Menschen stechen. Bei dem Stich entnimmt die Mücke dem Menschen Nährstoffe wie Blut und sondert Speichelsekret ab, woraus die Schwellung resultiert.

Wie aus dem PK bekannt, stechen Mücken vermehrt am Abend und an feuchten Gebieten, wie dem See. Die hohe Luftfeuchtigkeit am Abend und am See sowie die kühleren Temperaturen führen zu einer größeren Aktivität der Mücken. Dies lässt sich aus der Nachtaktivität und Abneigung gegenüber wärmeren Temperaturen der Mückenschließen.

Jedoch gibt es für den Menschen eine Möglichkeit, sich gegen die Angriffe zu schützen. Das Mückenspray überdeckt die ausgesendeten Informationen des Menschen, die auf die

Mücke anziehend wirken und den Menschen für sie somit uninteressant werden lassen.

Wie interessant die Menschen jeweils für die Mücken erscheinen, und somit häufiger als andere von ihnen gestochen werden, hängt von der Individualität des Menschen ab. Da jeder Mensch einen anderen Körpergeruch hat und unter unterschiedlichen Bedingungen unterschiedliche Mengen an Schweiß absondert, werden die Mücken von einigen Menschen mehr, von anderen weniger angezogen.

VON ALLEN ERSTELLT!!!

Generating a general witting explanation

They only wrote the general explanation for their phenomenon on the *Etherpad*. There was no discussion regarding the aspects of the biology core ideas helpful to unpack the causal chains in their phenomenon.

<u>Nummer</u> 1	<u>Teilfragen</u> Warum stechen Mücken?	Aspekt der KI, der der Konstruktion des/der Teilmodells/-erklärung zugrunde liegt Voneinander abhängige Beziehungen in Ökosystemen, Materialkreisläufe und Energieübertragung in Ökosystemen	Establishing the stages of the modeling- based investigation	All participants contribute to the <i>Data Collection</i> <i>Table.</i> <i>Interestingly,</i> <i>intermediate</i>
2	Warum stechen Mücken am Abend häufiger?	voneinander abhängige Beziehungen in Ökosystemen	Developing a sequence of partial questions	questions 1 to 3 are related to the focused biology core idea (ecosystems resilience), but questions 4 and 5 are about another core idea (information processing). This is important because, somehow, pre- service teachers open up possibilities
3	Warum kommen Mücken vermehrt am See vor?	voneinander abhängige Beziehungen in Ökosystemen		
4	Warum werden manche Menschen öfter von Mücken gestochen?	Informationsverarbeitung		
5	Was bewirkt das Mückenspray?	Informationsverarbeitung		for their planning. The information processing core idea amerges as relevant
				emerges as relevant as the group identified that understanding what happens with the information dimension is critical for engaging students

		appropriately in the modeling-based investigation.	
Dana   <u>studip</u>   02. Jul 2019, 17:36	Generating a	• They start working	
<u>Teilerklärung zu Teilfrage 1</u>	witting explanation including aspects of the biology core ideas	in the Forum for the	
Die Mücken nehmen die Informationen der Menschen wie den Kohlenstoffdioxidgehalt des Atems, die im Körper enthaltenen Fettsäuren und der produzierte Körpergeruch in Form von Schweiß aktiv wahr und reagieren darauf mit ihrer Angriffslust.		following the thread "Developing partial TBs-Model-	
Grund für diese Motivation ist der Drang, sich zu vermehren und ihre Brut zu ernähren. Daran lässt sich zeigen, dass nur die Weibchen stechen.		explanations integrating all the	
Marie   <u>studip</u>   02. Jul 2019, 17:52		aspects of the biology core idea"	
Teilerklärung Teilfrage 3		• Each group's	
Mücken haben ihre Brutplätze am See und ziehen ihre Larven dort groß. Zudem herrscht am See eine höhere Luftfeuchtigkeit, welche die Mücken präferieren.		participant leads one of the framed intermediate questions. Each	
Figure 3. Partial explanatory model that represents the third partial question	models	leader guided with her question the	
Tutfrage 3 : Worrum Kommen Muchen ver- mehrl om See vor? Teilmodelt 3		group's discussion along the Forum thread to establish the stages of the modeling-based investigation.	
Mucke		• It seems that the partial models (Figure 3-7) that correspond to each	

Natalie | <u>studip</u> | 02. Jul 2019, 19:36

# Teilerklärung zu Teilfrage 4

TF 4: Weshlab werden manche Menschen öfter gstochen als andere? Antwort: Manche Menschen werden öfter von Mücken gestochen als andere. Dies hat den Grund, dass jeder Mensch beinen eigenen Körpergeruch hat. Mücken reagieren auf Schweißgeruch und eine hohe Körpertemperatur. Zudem werden sie durch eine höhere Konzentration an Kohlenstoffdioxid im Atem angezogen.

Figure 4. Partial explanatory model that represents the fourth partial question



Johanna | <u>studip</u> | 02. Jul 2019, 20:09

# Teilerklärung Teilfrage 5

TF 5: Was bewirkt das Mückenspray? Beantwortung: Das Mückenspray hat die Wirkung, den die Mücken anziehenden Körpergeruch der Menschen nach Schweiß, Blut und Eisen zu überdecken und die Personen demzufolge uninteressant für die Mücken zu machen. intermediate question were developed collaboratively by the group face-toface and they upload the final versions of those models.

• In this case the participation in the Forum was asynchronous Figure 5. Partial explanatory model that represents the fifth partial question



Gina | studip | 02. Jul 2019, 20:27

# Teilerklärung Teilfrage 2

Am Abend ist die Luftfeuchtigkeit am Ort höher. Des Weiteren wird es am Abend kühler. Die Mücken sind am Abend aktiver und neigen zu kühleren Temperaturen.

Figure 6. Partial explanatory model that represents the second partial question



Johanna | <u>studip</u> | 03. Jul 2019, 20:23 Teilmodell zu Teilfrage 1

Anknüpfend an die Teilerklärung zur Teilfrage: "Warum stechen Mücken"

Figure 7. Partial explanatory model that represents the first partial question

