Assessing Students' Uncertainty during an Collaborative Inquiry-Based Learning Process in Go-Lab Climate Simulations

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Master Thesis (25 EC)

June 16th, 2025

Master of Educational Psychology

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Abstract

Uncertainty, often perceived as a barrier to learning, can catalyze deeper understanding and cognitive engagement when appropriately supported. This study investigates how Dutch secondary school students experience and manage uncertainty during collaborative inquiry-based learning within a digital climate simulation lab (Go-Lab). Drawing on Jordan's (2010) uncertainty management framework and the inquiry learning cycle model by Pedaste et al. (2015), the study analyzes 47 student chat episodes to identify the types and management strategies of uncertainty encountered. Four types of uncertainties emerged: Uncertainties related to the learning environment, course content, task assignment, and interpersonal relationships. Students predominantly employed a reducing strategy to manage these uncertainties, though instances of maintaining, ignoring, and increasing uncertainty were also observed, varying across different phases of the inquiry cycle. The inquiry process of investigation elicited the most uncertainty, especially related to the learning environment. Findings highlight the value of collaborative uncertainty dialogue significance and supported inquiry-based learning environments in promoting productive uncertainty management. These insights can inform the design of inquiry-based educational systems that encourage meaningful student engagement in the face of ambiguity.

Introduction

When learners experience cognitive challenges they have to engage in deep cognitive processes establishing deeper learning and understanding of the task (D’Mello et al., 2014). Such benefits of cognitive challenges have been theorized through cognitive conflict (Limón, 2001), impasses (VanLehn et al., 2003), cognitive dissonance (Festinger, 1957), socio-cognitive conflict (Mugny and Doise, 1978), and cognitive disequilibrium (Piaget, 1952). Uncertainty is a state of disequilibrium (Piaget, 1972), where learners experience doubt or are unsure about a situation (Jordan and McDaniel, 2014). When learners are uncertain they experience conflicts between what they know and their discoveries, unsure of their explanation (Lee et al. 2011; Potvin and Cyr, 2017). Encounters of uncertainty can encourage learners to recognize gaps in their understanding and consider alternative perspectives more thoughtfully (Kaur and Dasgupta, 2024).

While uncertainty is often perceived as an obstacle in education (Bonnet and Glazier, 2023), research suggests that it can provide enriching learning experiences when appropriately managed. Educational systems that encourage productive uncertainty - where students explore uncertain aspects of the learning content with appropriate guidance - have been shown to improve engagement and learning outcomes (Engle, 2011; Reiser, 2004; Gresalfi et al., 2009). Despite these benefits, many traditional education systems prioritize efficiency, structured instruction, and standardized testing, leaving little room to explore uncertainty (Chen, 2024). Chen (2024) describes how teachers face pressure to cover extensive curricula, limiting opportunities for inquiry-driven exploration. Standardized assessments encourage certainty, while not encouraging questioning, reflecting, and embracing mistakes as valuable learning opportunities (Chen, 2024; Rosen, 2019). Rosen (2019) claims that students may struggle to navigate ambiguity, change, and complexity, gaining limited experience in productively managing uncertainty and regulating their learning processes – valuable competencies for real-world problem-solving (Youngerman and Culver, 2019; Rosen, 2019). Productively managing these uncertainties establishes these moments of growth (Dewey, 1910). Consequently, advancing our understanding of how students navigate uncertainty in academic settings is essential for improving educational practices fostering meaningful, long-term learning outcomes (Jordan, 2010).

Dewey (1993) highlights that uncertainty naturally encourages inquiry, especially in complex problem scenarios. Inquiry-based learning is a teaching approach that encourages students to learn about new concepts and subjects by engaging in techniques similar to those used by scientists (Keselman, 2003). Throughout the inquiry process the learners formulate hypotheses and conduct experiments to build new knowledge (Pedaste et al., 2015). Actively introducing students to situations of uncertainty during Inquiry-based learning can stimulate students to make sense of new knowledge and establish new understandings (Manz, 2018; Watkins et al., 2018). This enables the students to reassess their understanding and develop new insights, promoting deeper learning strategies such as elaboration, self-explanation, and metacognitive reflection (Eysink and de Jong, 2012). Well-supported inquiry processes can, therefore, aid students in resolving those cognitive conflicts of uncertainty (Limón, 2001; Potvin, 2023), and when designed with sufficient support for managing uncertainties, inquiry-based learning enables the learners to build resilience and confidence in their problem-solving skills (Rosen, 2019). To foster these skills in the learning environment, it is essential to examine how learners currently manage their uncertainties during inquiry-based learning. Additionally, discovering how students manage uncertainties in these technological learning systems is valuable due to their increasing emphasis (Rosen, 2019), modifying classroom practices to.

Furthermore, while engaging in inquiry-based learning, students perform activities to build new knowledge and learn about new concepts and subjects. This introduces new uncertainties than before with direct instruction (de Jong et al., 2023), where students could experience uncertainty regarding different phases and collaborative features in the inquiry process. For example, students may experience uncertainty during the orientation phase, as they are introduced to new course content for the first time (Jordan, 2010). Additionally, uncertainties may arise during the investigation phase, where students may feel unsure about navigating and engaging with the learning environment effectively (Jordan, 2010). Based on Jordan’s (2010) research, students in the inquiry process may face uncertainties connected to their collaboration with peers while completing the learning tasks, evoking uncertainties connected to interpersonal relationships and assignment of tasks. To foster a valuable inquiry learning environment that encourages change and uncertainty, it is essential to examine the types of uncertainties students face during inquiry-based learning. This study aims to close the research gap between students’ uncertainty and inquiry-based learning. Therefore, we developed the following research questions.

RQ1: *What types of uncertainties do students encounter during inquiry learning?*

RQ2: *How do students manage uncertainties during inquiry learning?*

Theoretical Framework

Uncertainty Management

With the growing desire to facilitate meaningful learning opportunities in educational settings, there has been an increasing focus on developing methods to assess both the degree and source of uncertainty during the learning process (Sanchez et al., 2022). Successfully navigating uncertainty can be challenging, particularly for young learners (Kaur and Dasgupta, 2024). Uncertainty can result in extraneous cognitive load (Sweller, 1994), but can likewise bring up new possibilities of potential change and knowledge acquisition (Hatch, 1999). Encounters of uncertainty can encourage learners to recognize gaps in their understanding and consider alternative perspective more thoughtfully, ultimately supporting productive uncertainty management (Kaur and Dasgupta, 2024). This establishes learners curiosity, promote deeper learning (Lamnina and Chase, 2019), and fosters independent thinking (Feng et al., 2024).

Jordan (2010) proposes four uncertainty management strategies that learners engage in when experiencing uncertainty (see Table 1). Jordan's (2010) description is based on Babrow et al.'s (1998) conclusion that learners respond to uncertainty by *reducing*, *maintaining* and *increasing* the uncertainty. Lipshitz and Strauss (1997) found another strategy that revealed an approach of *ignoring* uncertainty. Research has shown that curiosity prompts the learners' brains to seek new information, aiming to *reduce* uncertainty and improve their ability to predict outcomes in their environment. (Fitzgibbon and Murayama, 2022; van Lieshout et al., 2021). Reducing uncertainty is known to be a prevalent strategy to manage uncertainty (Smithson, 1989; Jordan, 2010). Learners might engage in trial-and-error experimentation, request information and seek consensus with their peer collaborators. Another category of *reducing* uncertainty is to ask experts or other authority figures, such as teachers or researchers (Giddens, 1990). Nonetheless, Ison et al. (2021) illustrate that in complex and uncertain situations, only encouraging the *reduce* strategy to manage uncertainty can stimulate oversimplification, as such real-world situations can be not linear or easily managed. Therefore, they emphasize the possibility of allowing solutions to emerge naturally rather than following a predetermined sequence. Rosen (2019) argues that when students sustain their uncertainty throughout the learning process, transformation occurs as a result of gradual preparation. Sustaining uncertainty is described by the *maintain* uncertainty management strategy, defined by acknowledging the experience of uncertainty but delaying immediate action to resolve it. According to Arthur (1999) this strategy enhances learning, as the learner can use that observation at their next decision reducing possible wrong turns and still allowing multiple perspectives to move forward. Weick (1995) further embraces the decision to *maintain* uncertainty as a possibility for the learner to make sense of the situation and seek out multiple perspectives and solutions to the situation. The resulting delay of decision has likewise been identified as a valuable step during problem-solving (Glanville, 2007; Kilduff et al., 2000). Dismissing the introduced uncertainty and persisting with the next learning task is defined by the *ignore* strategy. Poli et al. (2022) highlights that although humans can generally manage uncertainty well, they prefer to pass off uncertainty when it is extreme. Lastly, Jordan (2010) describes the possibility of *increasing* uncertainty as a management strategy. By opening up the problem space and actively looking for alternative possibilities and opinions, the learner leaves room for questioning and stays open-minded (Bereiter and Scardamalia, 1993). Therefore, the learner *increases* uncertainty intentionally to acquire a more comprehensive view of the learning topic (Jordan, 2010). A detailed list of all categories of each uncertainty management strategy retrieved from Jordan (2010) is enlisted below (see Table 1).

Table 1

Strategies and Categories for Managing Uncertainty

Reduce	Ignore	Maintain	Increase
Analyze issues Test systematically Engage in trial-and-error experimentation Explain clearly Request information from group members Observe others Seek expert other	Keep going (persist, bluff) Avoid Pass off task Dismiss (do not consider introduced uncertainty)	Delay action, decision, or evaluation Acknowledge Express doubts	Open the problem space Purposefully seek multiple alternative action trajectories or opinions

Seek information from materials or texts
Ask for confirmation
Draw on past experience
Seek consensus
Refer to an authority figure

Note. From "Managing Uncertainty During Collaborative Problem Solving in Elementary School Teams: The Role of Peer Influence in Robotics Engineering Activity", by M.E. Jordan and R.R. McDaniel Jr., 2014, *Journal of the Learning Sciences*, 23(4), 490-536.

Uncertainty Management during Inquiry Learning

Research has displayed that students learn more in active learning classrooms compared to traditional lecture courses, even when they feel they learn less (Deslauriers et al., 2019). Inquiry-based learning inherently involves students' exploring and encountering uncertainty in the subject matter (de Jong et al., 2023), after studies indicating that learning environments that stimulate confusion, coupled with student engagement, positively correlate with deeper learning (Pekrun et al., 2002; Craig et al., 2004; Baker et al., 2010; D'Mello and Graesser, 2014). This holds when uncertainty is structured and supported - through scaffolding and teacher feedback - making it productive, not frustrating (de Jong et al., 2023). Inquiry learning recognizes the active role children play in their learning (Harlen, 2013) where students themselves identify problems, engage in experimentation, data observations and developing and answering research questions (de Jong, 2019, van Joolingen and Zacharia, 2009). Rather than directly providing correct answers, inquiry-based learning naturally encourages students to take an active role in constructing their own scientific understanding fostering deeper engagement (Engle and Conant, 2002). This concept originates from Dewey's foundational ideas (1933), where he described inquiry as a process involving active engagement with uncertainty. The inquiry process encourages the use of adaptive and independent thinking to manage uncertainty (Feng et al., 2024). Unlike traditional models that emphasize singular correct answers, Inquiry-based approaches promote flexibility, critical thinking, and multiple perspectives (Chen, 2024). This enables a balance between disequilibrium and structure, fostering continuous growth and equipping students to navigate the ongoing shifts and uncertainties in the modern world, to enhance students' ability to persevere in challenging situations and promote their capabilities that foster lifelong learning (Rosen, 2019). Effective uncertainty management may involve *reducing, ignoring, maintaining,* or *increasing* uncertainty, depending on the context (Babrow et al.1998; Kruglanski and Webster, 1996). Recent findings in developmental research indicate that humans strategically allocate their attention to the acquisition of information from their surroundings (Addyman and Mareschal, 2013; Liquin et al., 2021; Poli et al., 2020). These observations imply that humans are sensitive to the informational properties of the environment (Poli et al., 2022). Jordan (2010), similarly, indicates that students' uncertainty management strategies are shaped by the characteristics of the tasks they engage in. The learners' evaluation and attribution of the source of their uncertainty might influence their perception of potential actions, which, consequently, could influence their uncertainty management strategies (Jordan, 2010). Thus, when students encounter uncertainty during academic tasks, their uncertainty management might differ depending on whether they see the uncertainty as part of the learning environment or knowledge about the course content (Kahneman and Tversky, l982; McDaniel et al., 2003; Jordan, 2010). Exploring how the learning tasks of the individual inquiry phases interact with students' uncertainty management strategies is valuable to gain a deeper understanding on their impact on students' learning processes. Therefore, in the current research we will explore how students' manage their uncertainties in each individual inquiry phase to elicit a deeper understanding of students' uncertainties in the topic of inquiry-based learning.

Collaborative Uncertainty Management

Inquiry-based learning is typically conducted within a collaborative classroom setting, therefore completing collaborative learning tasks. Collaborative learning has be demonstrated to promote academic achievement (Springer et al., 1999), positive peer interactions (Loes et al., 2017), and critical thinking (Fung et al., 2016) while also enhancing communication and group skills (Terenzini et al., 2001). During collaborative learning, students feel like they are part of a learning group, as described by Tuckman's (1965) model of group development. Nonetheless, students can face challenges during collaborative learning (Feichtner and Davis, 2016). Kaur and Dasgupta's existing studies on peer learning and social regulation of learning (2024) emphasize the influence of peer responses in managing uncertainty in collaborative settings. Within the social dynamics of an academic collaborative group, students may be particularly mindful of their perceptions by peers, which can encourage them to modify their uncertainty management strategy (Jordan, 2010). For example, when uncertainty is acknowledged and addressed collaboratively, students are more likely to resolve uncertainty through explanation and discussion (Jordan, 2010; Kaur and Dasgupta, 2024). Therefore, the current research explores patterns and connections in collaborative uncertainty management, highlighting the role of productive group collaboration in helping students successfully navigate uncertainties in Inquiry-based learning environments.

Types of Uncertainties during Inquiry learning

Uncertainty orientations may change when the learner is fearful of failure of social rejection by their collaborators suggesting that their uncertainty management strategy depends on the context (Sorrentino and Roney, 2000). These individual and contextual element are likely to shape how learners manage uncertainty in collaborative tasks, including interpersonal relationships or aspects of the learning environment (Jordan, 2010). In Jordan's (2010) study students encountered uncertainty both in the project activities and within the collaboration dynamics as they worked to complete their engineering projects, exemplifying uncertainties toward the learning content, task assignment, interpersonal relationships, and the learning environment. For example, when unfamiliar learning tools are introduced, this will require the students to realign their collaborative task completion (Tuckman, 1965) and integrate their prior knowledge with new acquired knowledge (McClelland et al., 2020). To deepen the understanding of which specific types of uncertainties students face when moving through the inquiry learning process, our study investigates the types of uncertainties students experience in an Inquiry-based learning environment.

Supporting Uncertainty Management in Inquiry learning environments

Collaborative learning likewise has been displayed to increased learning gains when appropriately supported and designed (O'Donnell, 2006). Kaur and Dasgupta (2024) established that extended periods of uncertainty, especially in the absence of real time support, may have adverse effects and contribute to negative emotional outcomes. Establishing what challenges and uncertainties the students will face throughout inquiry-based learning can determine what support is needed for the students to address and manage their uncertainties (Lehrer, 2009; Metz, 2004; Manz and Suárez, 2018). Real time support is essential to increase productive and focused conversations (Kaur and Dasgupta, 2024). Even if humans can function well under uncertainty, Poli et al. (2022) displayed that there is an overall tendency of learners to avoid extreme forms of uncertainty. Therefore, a valuable learning environment induces moderate levels of uncertainty.

With the growing desire to facilitate meaningful learning opportunities in educational settings, there has been an increasing focus on developing methods to assess both the degree and source of uncertainty during the learning process (Sanchez et al., 2022). With the insights of the previous research we will look into the effects of the inquiry process on students uncertainty management strategies. In this research study, we present what types of uncertainties students encounter and how students manage these uncertainties as they navigate through the inquiry cycle in an online laboratory.

Methods

Design and Instrumentation

The study took place in the broader scheme of a multi-national education study called the “Dragon Gate Project”, collecting and comparing data from secondary school students in Taiwan, Germany and the Netherlands through a digital ecosystem called Go-Lab. Go-Lab facilitates inquiry learning spaces (ILSs) where students can learn STEM subjects through the engagement in experiments (De Jong, 2019). The current study developed a *Climate Change Eco-Lab* designed as a computer-supported collaborative learning (CSCL) environment where students could explore the impact of human activities on the environment including variables such as fossil fuels, deforestation and CO2 emissions. The students learned about their effects on the climate with the support of inquiry-based learning, requiring students to work as a team, completing collaborative and individual tasks. Lastly, the students engaged in a pre- and post-test on their knowledge on the effects of human activities on climate change to discover the learning outcome of the Eco-Lab. The current research works with a subset of this education study, using the chat tool of the Eco-Lab to research Dutch students’ uncertainties.

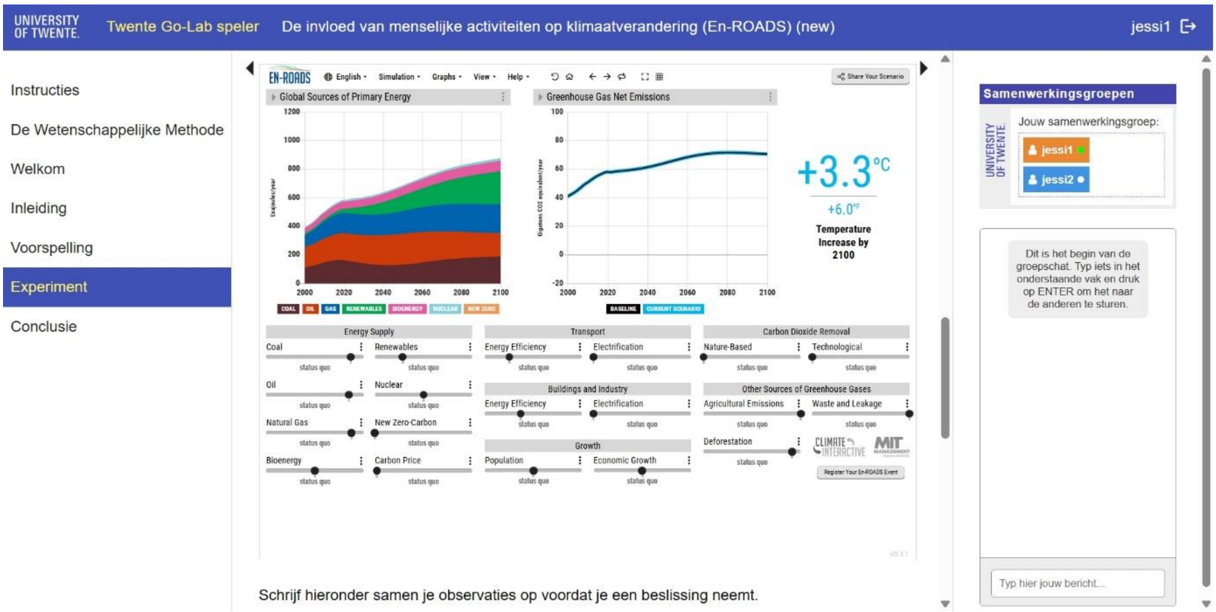
Procedure

Each participant spend approximately 115 minutes in total on the study, divided into 3 sessions. Each participant engaged in two 45 minute classroom sessions for the learning activities and an additional 25 minutes for pre- and post-intervention surveys. The scientific process of Inquiry-based learning was organized into connected inquiry phases forming the

Inquiry cycle, highlighting important aspects of scientific thinking (Pedaste et al., 2015). The students completed the Eco-Lab moving through the entire inquiry learning cycle. This was established by creating sub-sections that displayed the individual inquiry phases. To represent the inquiry cycle, the Eco-Lab is divided into 8 sections, taking the students through the inquiry cycle (see Figure 1; a detailed overview of all sections is provided in Appendix A). The following descriptions follow the framework from Pedaste et al. (2015). In the first inquiry phase the learner receives an orientation on the learning topic. The first four sections called "Instruction", "The Scientific Method", "Welcome", and "Introduction" are designed to introduce the student to the learning environment and the topic of climate change to represent the inquiry phase of Orientation. The following section called "Prediction" represents the Conceptualization phase where students create their hypotheses on climate change variables. The brain is continuously engaged in enhancing its ability to predict environmental event (Clark, 2013). This enables learners to navigate and interact efficiently with familiar settings, where sufficient information is available to support optimal decision-making (Poli et al., 2022). In contrast, identifying effective strategies for information gathering in unfamiliar environments poses greater challenges (Baranes et al., 2014) which suggests that establishing a prediction in a novel environment might increase learners' uncertainties. The "Experiment" section represents the Investigation phase, allowing the students to investigate their hypothesis through an experiment. The Investigation phase reinvents the learners curiosity into an actionable process (Scanlon et al., 2011). The learners explore and observe different variable values through designing and conducting different experiments that are related to the defined research questions or hypotheses. The last section of the Eco-Lab called "Conclusion" represents the Conclusion inquiry phase, encouraging the students to make inferences from their investigation. The Discussion inquiry phase is represented by a chat tool the peer collaborators can use to discuss and communicate their work throughout all Eco-Lab sections.

Figure 1

Overview of the Eco-Lab including the Inquiry Sections and Chat Box Tool



Participants

The study in the Netherlands originally invited 78 students in three classes, and two pre university education classes (VWO) and one senior general secondary education class (HAVO). The first VWO class included 29 students (2 students were absent, a total of 27 students participated); the second VWO class included 25 students (6 students were absent, a total of 19 students participated); the HAVO class included 24 students (3 students were absent, a total of 21 students participated). This concludes a total of 67 students participated in the study (N=67). Among them, 17 students did not fill in the post-test, and 1 student did not fill in the pre- and post-test. This concludes a total of 66 students filling out the pre-test; but only 49 students filled out both the pre- and post-tests. The participants were secondary school students, ranging from 14 to 17 years old. The participants were randomly given a code name to log in to the Eco-Lab to be able to document their log files and textual chat records. Each participant was grouped together with one or two other participants in their same class, being able to complete the tasks at the same time and seeing each other's answers to the collaborative items. Each peer group then randomly got assigned to a experimental or control condition that was part of the larger experimental research. In the current study these two conditions are not further explored as the students' experience with uncertainty in both conditions turned out to be similar.

Data Analysis

The current study employs an exploratory research analysis, investigating uncertainty management during inquiry-based learning through the qualitative data derived from the chat tool. Content analysis of the chat data includes coding, summarizing and evaluating the frequencies of these codes to explore connections and valuable insights (Strijbos et al., 2006).

Step 1: Finding Markers in the Chat File

We assessed students' uncertainty by scanning the data for paralinguistic and linguistic uncertainty markers, using Jordan's (2010) summarized list of uncertainty makers as a guideline. See the full overview of markers that were used in the current study and their initial source in the table below (Table 2).

Table 2

Markers of Uncertainty

Marker	Source
Paralinguistic Markers	
Errors, disfluencies, hesitations (fillers such as "well…", repeats, false starts, "um", "er")	Barr (2003), Maclay and Osgood (1959)
Linguistic Markers	
Verbal hedges, Parenthetical adverbs that convey psychological uncertainty ("I guess", "I doubt") Modal verbs and auxiliaries that convey referentially ambiguous uncertainty ("may", "might", "perhaps")	Feldman and Wertsch (1976), Green (1984), G. Lakoff (1973), Turner and Pickvance (1973)

Questions; tag questions ("It goes this way, right?") Conditionals, hypotheticals ("if…")	Bernstein (1962), Turner and Pickvance (1973)
Approximators ("It's pretty long") Qualifiers, Rephrasing	McFadyen (1996), Meaney (2006)
Explicit self-reports of mental states reflecting metacognitive awareness of uncertainty ("I'm not sure", "I'm confused")	Anderson et al. (2001)

Step 2: Reading through the textual chat file

We read through the complete textual chat file to find additional moments of uncertainty that have not been shown through the search for uncertainty markers.

Step 3: Establishing the Concrete Uncertainty Episodes

We established the concrete unit of analysis by defining the beginning and end of a concrete uncertainty episode: *An uncertainty episodes starts when a new topic arises and uncertainty is expressed. The episode ends when the topic ends.* To make the analysis easier, we translated every uncertainty episode from Dutch to English using our own knowledge skills, Chat GPT and Google Translate.

Step 4: Analysis of Inquiry Phases

To investigate in which inquiry phase the students experienced their uncertainty, the log files of the ILS are used. The investigation of the uncertainty units uses the log files of the ILS to determine which inquiry phase is connected to each unit. The units were coded for the Eco-Lab sections representing each inquiry phase: Orientation (Instruction, Scientific Method, Welcome, Introduction), Conceptualization (Prediction), Investigation (Experiment), and Conclusion (Conclusion). To ensure the validity of the analysis, the Discussion phase is not included in the Eco-Lab analysis, as it was not represented as a distinct section within the ILS.

Given that the Orientation phase comprises multiple sections and, consequently, a greater number of tasks compared to the other phases, these sections are analyzed, coded and compared individually. This approach accounts for the extended time spent in the Orientation phase and the consequent higher frequency of uncertainty units during this phase.

Step 5: Analyzing the Types of Uncertainties

The coding scheme and themes used in this paper is based on literature and data on grounded theory, extracted from Jordan's (2010) research. The current study uses four codes, adjusting and confining them to the uncertainties that were expressed in the established uncertainty episodes. The four codes arose from analyzing the individual uncertainty units and the context in which the uncertainty arose (see Table 3).

Table 3

Coding the Types of Uncertainty

Type of Uncertainty	*Code Definition*
Learning Environment Uncertainty	Uncertainty is expressed about the Learning environment (How to use tools in the ILS, e.g. simulator, adjusting variables, understanding the tasks, problems with the LE)
Course Content Uncertainty	Uncertainty is expressed about the Course content (Discussions about climate change, course material, or related topics)
Interpersonal Relationship Uncertainty	Uncertainty is expressed about the work of the other group member

Task Assignment Uncertainty	Uncertainty is expressed about the assignment of task between the group members (How students divide tasks or roles in the group)

Step 6: Analyzing the Uncertainty Management Strategies

After coding for the type of uncertainty, the next step was applying codes related to the four uncertainty management strategies derived from Jordan's (2010) dissertation study: Reduce, Ignore, Maintain, Increase. Each strategy defines a different approach to managing uncertainty and multiple categories were considered to deepen the investigation of students uncertainty management strategy (see table 2).

Step 7: Interrater Reliability

To ensure interrater reliability, 20% of the uncertainty units were coded in collaboration with two other researchers, one PhD student and one expert in the field of uncertainty management and inquiry-based learning. This involved the iterative process of 2 rounds with the first researcher and 6 rounds with the second researcher of refining and adjusting the uncertainty units and code definitions until reaching consensus. Disagreements were resolved through discussion and the final codes were applied to the rest of the data.

Step 8: Inquiry Cycle and Uncertainty Management Exploratory Analysis

To exemplify the strategies and types of uncertainties observed in the ILS, one unit of each uncertainty management strategy per inquiry phase is illustrated in the Results section of this paper. The chats are examined to explore the context and purpose of uncertainty in the conversations. Statistical analysis was used to determine the frequency, means and standard deviations of the types of uncertainty and uncertainty management strategies during the inquiry learning phases. Overviews are created to display the analysis of students' uncertainties during the inquiry learning process to investigate possible connections and patterns of the uncertainty management strategies and types of uncertainties experienced by the students. The exploratory results are documented in the Results section of this paper. Connections and patterns derived from the chat analysis are integrated in the Discussion section of this paper.

Results

To examine how students manage uncertainty during inquiry learning, we analyzed the situations in which the students encountered uncertainty and the strategies they used to manage it. The results of the current study are connected to the individual phases of the inquiry learning cycle to explore the contextual and phase-specific variations. The analysis of the students' chat tool identified a total of 47 uncertainty episodes in the conversations. The highest number of uncertainty instances was found in the Investigation phase (N=17), followed by the Orientation phase (Introduction: N=10; Welcome: N=8), the Conceptualization phase (N=8), and finally, the Conclusion phase (N=4) (see Table 4 and 5). No instances of uncertainty were observed in the first two sections of the Orientation Inquiry Phase (Instruction: N=0; Scientific Method: N=0), therefore being excluded from the further coding analysis.

RQ1: *What types of uncertainties do students encounter during inquiry learning?*

To explore the first research of what types of uncertainties students encounter during inquiry learning we coded four types of uncertainties throughout the uncertainty episodes. Most uncertainties displayed in the chat conversations revolved around the *Learning environment* (LE Uncertainty), followed by *Course content* (CC Uncertainty). Most *Learning environment* uncertainties occurred in the Investigation Inquiry phase, while most *Course content* uncertainties appeared in the Introduction inquiry section. Only a few uncertainty episodes emerged in the context of *Task assignment* (TA Uncertainty) and *Interpersonal relationships* (RE Uncertainty) (see Table 4).

Table 4

Frequency of Types of Uncertainties during Inquiry Phases per Uncertainty Episode

Type of Uncertainties	Orientation (Welcome)	Orientation (Intro)	Conceptualization	Investigation	Conclusion	Total
LE Uncertainty	5	4	4	16	2	31
CC Uncertainty	0	6	3	1	2	12
TA Uncertainty	2	0	1	0	0	3
RE Uncertainty	1	0	0	0	0	1

RQ2: *How do students manage uncertainties during inquiry learning?*

To answer the second research question of how students manage uncertainties during inquiry learning, we analyzed the frequency of uncertainty episodes that were coded for four uncertainty management strategies. All four strategies for managing uncertainties, meaning *Reducing*, *Ignoring*, *Maintain*ing, and *Increasing* uncertainties were visible in the analysis of the current student chat conversations. Among the uncertainty management strategies, *Reduce* was the most frequently used strategy across all inquiry phases, followed by *Maintain*, *Ignore*, and lastly, *Increase* (see Table 5).

Table 5

Frequency of Uncertainty Management Strategies during Inquiry Phases per Uncertainty Episode

Uncertainty Strategy	Orientation (Welcome)	Orientation (Intro)	Conceptu alization	Investigat ion	Conclusion	Total	M	SD

Reduce	5	8	6	9	3	31	6.4	2.14
Ignore	0	1	1	4	0	6	1.2	1.47
Maintain	3	0	1	3	0	7	1.2	1.36
Increase	0	1	0	1	1	3	0.4	0.49

Table 3 further presents the frequency and variability of uncertainty management strategies (*Reduce*, *Ignore*, *Maintain*, *Increase*) determined in the textual chat file across all inquiry phases. The *Reduction* of uncertainty has the highest mean frequency, indicating it is the most commonly used strategy by the students. To provide further insights into these findings and explore the relationship between the individual uncertainty management strategies and inquiry phases, examples of each combination observed in the textual chat file are presented in the following section. Each episode displays a separate group containing two students.

Chat analysis of Uncertainty Episodes per Inquiry Phase

Orientation Inquiry Phase (Welcome Section)

The deeper analysis of the chat starts in the Welcome section representing the Orientation inquiry phase as this is where uncertainties were first observed in the chat file. In the Welcome section, students encounter their first set of active tasks. While the earlier sections "Instruction" and "Scientific Method" involved simply reading and understanding the effects of human activities on climate change, they are now required to respond to questions, sharing their own observations on the topic. Through consistent dialogue, sharing knowledge, and maintaining open communication about the tasks they encounter, the following student group engages in a *Reduce* strategy to manage their experienced uncertainty in this section.

Episode 1.

Jara: Why is this so unclear?

Josh: I don't know; I have no idea what I'm supposed to do right now.

Jara: Yeah, me neither.

I'm reading the scientific method now.

Josh: I'm already answering some fun questions.

Jara: Which ones?

Josh: Under "Welcome," at the bottom.

Jara: Ohhh.

Josh: What kind of questions are these?

Jara: No idea.

Really vague.

Josh: Where are you?

We're supposed to answer questions together or something.

Jara: I'm on 2 now.

Which ones are supposed to be done together?

Josh: Yeah, like in the Introduction or something.

Jara: Ohh.

I'll finish 3 real quick, and then we'll do the Introduction?

Josh: Do you see my answers for 2 and 3?

Yeah, sounds good.

Jara articulates uncertainty, prompting a response from her peer collaborator Josh, reflecting their mutual experience of uncertainty. The group collectively expresses uncertainty about the *learning environment* and the *task assignment*. By openly stating their uncertainty, they aim to gain clarity and determine the appropriate approach to addressing the questions. Their exchange of information and mutual requests for guidance suggest the use of a *Reduce* uncertainty management strategy. The group proceeds systematically, addressing each questions step by step while collaboratively assigning and confirming tasks. They actively seek consensus to navigate the tasks in correspondence with one another which allows them to create a clear approach to progress through the Eco-Lab. Their mutual use of the *Reduce* uncertainty management strategy seems to be helpful in resolving any uncertainties that Jara and Josh come to face throughout the first inquiry sections. The next uncertainty management strategy is *ignoring* uncertainty. However, no instances of the *Ignore* strategy were observed in the welcome section.

Students who engaged in the *Maintain* strategy appeared to be uncertain about the learning environment itself – still acclimating to its features - rather than the tasks of the inquiry phase. This scenario illustrates how uncertainty about the learning environment can manifest as *interpersonal relationship* uncertainty, defined by a team member's expression of uncertainty regarding the work of the other group member. The expression of a lack of consensus with the team member underscores the students' desire for correspondence and collaborative effort between the peer collaborators. This episode highlights the relational uncertainty that can arise between collaborators at the beginning of the inquiry cycle.

Episode 2.

Romee:	Can you see what I'm writing now?
	Because I can see your cursor.
Ellie:	Yes, I see it
Romee:	Then why aren't you doing anything?
Ellie:	I am?
	I've filled out 1 and 3
Romee:	I don't see that
	You just said that you could see it
Ellie:	I can see your thing

In this interaction, Romee expresses uncertainty and frustration about the *Task assignment*, specifically regarding Ellie's task completion. Romee is unable to view Ellie's answers, whereas Ellie can see Romee's responses. The technological issue encourages Romee to assume that Ellie is not collaborating effectively, and expresses disagreement despite Ellie's assurance that she has completed her tasks. Romee's expression of doubt and persistent lack of consensus, exemplify the *Maintain* strategy, as uncertainty is acknowledged but resolution is delayed. No instances of students employing *Increasing* uncertainty as a management strategy were observed during the Welcome inquiry phase. This phase is characterized by the students' initial engagement with a new and unfamiliar *Learning environment*. Consequently, the uncertainties that arose in the chat conversations were often related to navigating the *Learning environment* itself.

Orientation Inquiry Phase (Introduction Section)

The Introduction inquiry section is the first section where collaborative tasks are introduced, likely directing students' uncertainty toward this new component of the *Learning environment*. By initiating the collaborative tasks of the Eco-Lab, the Introduction section makes the chat box a more integral tool for interaction, introducing greater possibilities for joint task completion. This conversation highlights two students encountering confusion about the visibility of their collaborative task responses and using the *Reduce* strategy to manage their uncertainties.

Episode 3.

Lara:	I can't see yours because it's for individual use.
Sevgi:	Oh, I didn't realize that.
Lara:	It's acting weird for me. I can see your part about what you've learned about climate change and so on, but not the rest.
Clair (A):	4a15, do you agree or disagree with your partner?
Sevgi:	Oh, huh.
	Maybe you should ask about that.
Lara:	Yeah, sure.

Lara shares their observation that she cannot view Sevgi's answers because the current task is an individual, rather than a collaborative, activity. She further expresses frustration, stating that the Eco-Lab does not seem to function properly for her, as she is unable to see Sevgi's contributions on other collaborative tasks. Although Clair attempts to prompt further discussion, the collaborators do not engage with the conversational agent's question, likely because they are preoccupied with managing their uncertainty. To address Lara's uncertainty, Sevgi proposes seeking help or direction from the teacher or researchers. This approach aligns with the *Reduce* uncertainty management strategy, as seeking guidance from an authority figure is a defined category within this strategy. The following episode illustrates the use of the *Ignore* uncertainty strategy during the Introduction section.

Episode 4.

Nynke:	I find it a bit vague because I don't really know. There's a question here: Do you agree with your group's viewpoints? But what viewpoints? What is that about? (: Has your way of thinking changed after watching the video? Does the information in the video match what you or your group thinks? For this, I entered: "Yes, kind of. I'm now even more concerned about climate change, especially the role humans play in it. (Throughout history, you also see that humans have played an *Increasing* role.)"
Clair (A):	4a13 (Beaudi) , do you agree or disagree with your partner?
Nynke:	I'm at the section called: Prediction.
Beaudi:	Yeah, those viewpoints—I guess just what we both said so far.
Nynke:	Yeah, I think so too.

Nynke, experiencing uncertainty, explains her confusion and seeks clarification from her collaborator, Beaudi. However, Beaudi does not respond immediately, instead continuing his individual work and dismissing the uncertainty raised by Nynke. After several additional messages, Beaudi finally replies with a vague comment that lacks a clear explanation. By avoiding Nynke's expressed uncertainty and prioritizing his own tasks, Beaudi demonstrates the *Ignore* uncertainty strategy. Despite this, Nynke accepts this response and resolves her uncertainty without gaining a comprehensive understanding. This interaction suggests that some students' primary objective may have been completing the tasks in the Inquiry Learning Space (ILS), rather than fully engaging with the topic or collaborative aspects of the project. Nynke's expression of uncertainty might be motivated by her desire to answer a task requiring her opinion on the group's viewpoints. To do so, she relies on her collaborator's input, using the chat function to communicate a desire for explanations and clarity. In response, Clair intervenes, seemingly trying to reengage Beaudi by directly addressing him and asking whether he agrees with Nynke. Clair's approach is notable, as it aligns with Nynke's expressed uncertainty revolving around agreement seeking and understanding the group's viewpoints. Interestingly, even though Beaudi's engagement is limited and his responses are vague, Nynke continues to update him on her progress in the subsequent tasks and informs him when she moves to the next inquiry phase. Despite not receiving the same collaborative effort from Beaudi, Nynke remains committed to *Maintain*ing communication, seeking consensus, and fostering collaboration, employing the *Reduce* uncertainty management strategy. This persistence contrasts with Beaudi's apparent focus on completing the tasks independently, seemingly prioritizing efficiency over the collaborative learning objectives of the Eco-Lab. However, later in the conversation, Beaudi demonstrates a shift in behavior. When he experiences uncertainty he does seek help from Nynke, engaging more actively in the chat and recognizing its value for the collaborative tasks. This change marks the groups' transition to the

Increase uncertainty strategy, which will be exemplified in the Investigation Inquiry phase (Episode 13). There are no instance of students employing the *Maintain* uncertainty strategy during the Introduction section. Besides the employment of the *Reduce* strategy, this section includes only one instance of the *Ignore* strategy and one instance of the *Increase* strategy.

In this following episode, the expression of uncertainty serves the purpose of fostering a deeper understanding of the *Course content*.

Episode 5.

Gracy: I’m now at the Introduction
Do you understand question 1 with the standpoint?
What is our standpoint?
Stella: What do you think is a good standpoint
Gracy: That climate change needs to be addressed
Stella: OK, that’s good, but how
Flying less?
Gracy: Using biofuels
Stella: That’s good
Gracy: Yes

Gracy begins by informing her peer collaborator, Stella, that she has moved on to the next inquiry section of the Orientation phase, the Introduction section. She inquires whether Stella understands the first question. Gracy expresses uncertainty about the meaning of the question, which requires her opinion on the group’s standpoint – a reference to the questions they previously answered as a group within the same inquiry phase. In response, Stella challenges Gracy to think critically and propose a sufficient group standpoint. Gracy suggests an idea that Stella responds to positively, but rather than concluding the discussion, Stella expands the problem space by prompting Gracy to provide further details about her standpoint. This exchange seems to encourage both collaborators to introduce and refine their ideas, ultimately reaching consensus on a shared standpoint. This episode illustrates the use of the *Increase* uncertainty strategy, as the purposeful discussion and exploration of the task not only resolved their initial uncertainty but also enhanced their understanding of the *Course content*. The interaction between Gracy and Stella highlights how engaging in deeper conversations can foster more detailed responses, improved comprehension, and effective collaboration on the task. Additionally, this episode exemplifies a interaction between two students initiating their group work with a constructive and collaborative approach.

Conceptualization Inquiry Phase (Prediction section)

Episode 6.

Emily: Hey, do you understand the drag-and-drop exercise in "Prediction"?

Because I don’t get what you’re supposed to do?

Luisa: You have to drag a word behind "if," like I have now: "If deforestation decreases, then bioenergy *Increase*s." Something like that.

like this

Emily: Oh, okay, but I can’t see what you’re doing, I think.

Luisa: I also can’t see what you’re doing

I’m going to "Experiment" now

Emily: Okay, Me too

In the current Conceptualization phase, Emily expresses uncertainty about a drag-and-drop exercise, prompting her collaborator, Luisa, to provide a clear explanation of the required action. Although Emily demonstrates understanding of the task, she continues to highlight a technical issue, specifically the difficulty in viewing all parts of the *Learning environment*, including Luisa’s answers. This technical issues appears to persist throughout the study due to inconsistent internet connectivity in the school environment. Luisa acknowledges Emily’s concern, reassuring her of experiencing the same difficulty, before confirming her readiness to transition to the Experiment phase. This exchange successfully resolved the uncertainty, enabling both collaborators to progress to the next inquiry phase. The active engagement and acknowledgment of each other's concerns exemplify the *reducing* of *Learning environment* uncertainties, reinforcing their collaborative efforts and mutual support.

The following episode provides a concise example of the *Ignore* uncertainty management strategy observed in the Conceptualization phase. The Prediction section marks the first moment students are required to use a drag-and-drop tool rather than responding with written text. In this exercise, students can drag-and-drop variables related to climate change and combine them to form predictions.

Episode 7.

Eliza: Do you understand that Prediction? Because I don't get it.

When Eliza expresses confusion about the *Course content*, her collaborator Justus does not respond, effectively avoiding the uncertainty she raised. Later, when Eliza poses another question, Justus provides a response, though it does not address her earlier expressed uncertainty. Despite Eliza's attempts to *reduce* uncertainty, this unit is defined by Ignoring uncertainty, as Justus avoids providing a clear explanation or directly engaging with the expressed uncertainty. Eliza's initial uncertainty concerns the broader scope of the inquiry phase rather than a specific task, which may explain why her collaborator did not respond to her question. The question's broad and less defined nature likely made it more challenging for Justus to address effectively. When Eliza follows up with a more focused and concise question, Justus does provide a response.

In this next episode, the collaborators are engaged in different phases of the Inquiry cycle - Jip in the Conceptualization phase and Paul in the Investigation phase – yet both express uncertainty about the *learning environment*. Jip initiates the exchange by sharing ideas and seeking both confirmation and additional input from Paul to better understand the drag-and-drop exercise required in the Conceptualization phase.

Episode 8.

Jip:	I really don’t understand this assignment
Paul:	Me neither
Jip:	Are we supposed to randomly pick things? And just drag them?
Paul:	Clair, where are you when I need you
	You’re still at "Prediction"
	I’m at "Experiment"—this one is really impossible
Jip:	Yeah, that’s the table, right?
Paul:	Yeah
Jip:	We only have 2 minutes left
	No one’s going to finish this
Paul:	I’m skipping it

Jip explicitly expresses uncertainty, aiming to receive clarification and guidance from Paul on how to complete the exercise effectively. When Paul responds, he acknowledges the uncertainty but delays taking immediate action to resolve it. Instead, he voices his own doubts, redirecting attention to Clair, and mentioning the greater difficulty that he experiences in the subsequent Investigation phase. Faced with time constraints, the group ultimately agrees to skip the Experiment phase entirely and conclude the Eco-Lab. By delaying action and evaluation to address their uncertainties, the group exemplifies the *Maintain* uncertainty strategy, which involves sustaining rather than immediately resolving the uncertainty. Although Jip’s initial intention was to *Reduce* uncertainty by seeking information from his collaborator, Paul’s approach seems to shift the group’s strategy. This shift likely reflects his attempt to adapt his approach to achieve consensus with Paul and navigate the collaborative process with the uncertainties they face. No episode was identified in which students engaged in the *Increase* uncertainty management strategy during the Conceptualization phase of the inquiry cycle.

Investigation Inquiry Phase (Experiment section)

Unlike previous tasks, which involved answering discrete questions or developing a hypothesis on climate change, the Investigation Inquiry phase introduces a more complex, dynamic activity. Students can adjust multiple variables to observe their effects on future climate scenarios, each configuration of variables displaying their visible, distinct impact. The students then document their findings in an observation table.

Episode 9.

Tina:	now Experiment?
Caro:	what is this
Tina:	no idea
	super weird
Caro:	I don’t get this at all
Tina:	you have to drag those things above or something, then write it down
Caro:	oh, okay
	how many do you think?
Tina:	4 or something
Caro:	[poop emoji]
Tina:	oh yeah
Caro:	yeah
	I think it’s good like this, right?
Tina:	yeah

In this group both collaborators express uncertainty regarding the drag-and-drop exercise and the accompanying observation table in the Experiment phase. Tina offers a clear explanation of the task requirements, while Caro seeks additional clarity regarding the scope of the task. Ultimately, Caro requests confirmation on whether the Experiment phase has been completed, ensuring they can proceed collaboratively to the next inquiry phase. Despite the uncertainties expressed by both group members, they actively share ideas, voice their doubts, and pose questions to one another, demonstrating their use of the *Reduce* uncertainty strategy. They work together as a unit, displaying that while the Experiment inquiry phase culminates more challenges, it seems to strengthen the collaboration and team work efforts in the groups, further, highlighting the value and necessity of collaborative problem-solving. By navigating these uncertainties together, the group demonstrates their ability to work collectively toward achieving their ultimate goal of completing the project.

The following example highlights a group that first enacts in *Ignoring* and *Maintaining* their uncertainties first, expressing their desire to discontinue the project but then changing their strategy to *Reduce* their uncertainty instead.

Episode 10.

Luuk: Then you move on to the Experiment.

Sam: Yeah.

Luuk: What the heck is this?

What

the heck?

This table.

Bro.

Sam: Yeah, I don’t understand anything about this.

Luuk: I’m stopping.

Bye.

Sam: Don’t leave me behind!

Hey, I really don’t understand any of this.

Luuk: Okay, you have to fill in the energy supply.

Above the task.

So:

Coal,

oil,

Sam: ah, okay.

As the group transitions to the Investigation phase, Luuk expresses confusion regarding the upcoming task. Sam agrees with the expressed doubt, reinforcing Luuk's uncertainty, thereby *Maintain*ing Luuk's uncertainty rather than resolving it. This dynamic is followed by an announcement from Luuk to discontinue the project. However, the interaction takes an unexpected turn when Sam voices his concern about being left to complete the task alone. This prompts Luuk to re-engage with the activity, ultimately providing a detailed explanation on the execution of the task. While the dialogue itself does not explicitly demonstrate task completion, the ILS analysis indicates that the group successfully completed the observation table, thereby resolving their uncertainty about the *Learning environment*. This episode exemplifies the *Reduce* uncertainty management strategy, as the group navigates their doubts through collaborative information exchange and explanation.

The following example displays a brief uncertainty conversation that precedes the premature submission of tasks before completing the Investigation Inquiry phase.

Episode 11.

Ann: You know what? I'll just move on to the Experiment. I can't see what you wrote.
But what did you do there?
I'll just write something in for myself.
Michael: I just filled it in the way I thought it would make sense.
Ann: I don't understand the Experiment part.
I'm logging out.

Ann initiates a discussion about transitioning to the Experiment section in an effort to comprehend the requirements of the inquiry phase. After waiting for a response from her peer collaborator, Michael, she indicates her intention to proceed independently, revealing that Michael is avoiding her expressed uncertainty. Previously, Ann encountered a technical issue in the conceptualization phase, where she was unable to view Michael's contributions. She appeared to *maintain* this uncertainty, likely attributing it to a technical problem. However, upon entering the Investigation phase, she desires clarity on Michael's answers, aiming to manage and resolve her uncertainty. Despite her efforts to engage Michael in collaboration, he does not respond, dismissing her expressed uncertainty and demonstrating the strategy of *ignoring* uncertainty. Recognizing Michael's lack of engagement, Ann, likely driven by a solution-focused mindset, proactively decides to generate an answer herself. After a delay, Michael responds but offers no clarification or explanation regarding the task, opting instead to focus on his individual work without actively addressing the expressed uncertainty. This lack of collaboration seems to have an affect on Ann, as she continues to express confusion about the investigation phase. Eventually, she decides to log out of the Eco-Lab, likely realizing that she will not receive the support or explanation desired from her collaborator to complete the concluding tasks. Consequently, Ann appears to opt for *ignoring* uncertainty as a strategy, choosing to disengage from the task, following Michael's choice to *ignore* her expressed uncertainty previously.

In the following episode, Lois and Niall express uncertainty regarding the Investigation Inquiry phase and engage in the *Maintain* strategy.

Episode 12.

Lois:	Hi.
Clair (A):	This conversation is interesting. Could one of you summarize what you've covered so far?
Niall:	Heyy.
Lois:	I don't want to anymore.
	I don't get it.
Niall:	Me neither.
Lois:	We haven't covered anything, Clair.

Niall: I don’t understand, Clair.

Lois: Stupid Clair.

Niall: Dumb Clair.

Lois: Explain, Clair.

What am I supposed to do?

Niall: Clair, you’re useless.

Lois: Agreed.

What the flip?

Niall: Erhm.

Why is this so confusing?

When Clair prompts them to summarize their progress, they direct frustration toward her, using disparaging remarks while also asking her for clarification. Not answering Clair’s question, Lois explicitly states that she does not want to continue working on the Eco-Lab and does not understand the task. After attempting to blame Clair and asking her for an explanation of the task, without receiving a response, they continue progressing through the tasks. The collaborators use the chat primarily to express uncertainty rather than to exchange information or seek solutions. Despite acknowledging their uncertainties, they delay any visible action or evaluation to resolve it and instead use a *Maintain* strategy to manage their experienced uncertainty. This interaction suggests that while the collaborators expressed frustration and blame, categorized for the Ignore strategy, their acknowledgement of uncertainty is defined by the *Maintain* strategy. As a result, their uncertainty regarding the *Learning environment* and *Course content* remains unresolved.

The following episode of *Increasing* uncertainty follows a previous conversation of the same group using the *Ignore* strategy during the Orientation Inquiry phase (see Episode 4).

Episode 13.

Beaudi: I don’t understand what we’re supposed to do.

Nynke:	Me neither.
Beaudi:	At Experiment.
Nynke:	What is the decision we need to make?
	About what?
	And that diagram is weird too.
	Observation of what?
	I have now: If nuclear energy *Increase*s, then greenhouse gas emissions *Increase*.
Clair (A):	4a13, how do your ideas connect to what 4a05 just said?
Nynke:	Idea.
	Subsidy—what do they mean by that?
Beaudi:	Where does it say that?
Nynke:	In the column I'm at now.
Beaudi:	Oh, money, I think.
Nynke:	It says something about subsidies.
Beaudi:	Like a reward.
Nynke:	Okay.
	So in the column next to it, do you need to give a reason why deforestation is happening or something?
Beaudi:	Yeah, I don't understand that either.
Nynke:	I don't get any of it.
	I don't understand this entire chart.
Beaudi:	Maybe how you achieve the action.
Nynke:	Oh.
	Okay.
	And where do you get that variable from?
	From the Prediction, those words?
Beaudi:	You have something above there.
	And you need to click on "close."
	Close.
Nynke:	But do we have three now?

Is that enough?

Should I go to Conclusion then?

Beaudi: I think five is good.

Beaudi enters the Experiment inquiry phase and notices some doubts on what to do. Despite showing to work mostly alone, he now uses the word we, highlighting group collaboration, which contradicts his visible behavior and collaboration portrayed through the chat. It seems that now that he experiences uncertainty he sees the value of the chat box and being able to reach out to his collaborator, Nynke. The following unit highlights how participants employed the *Increase* strategy to manage uncertainties during the Experiment phase. Initially, both group members struggle to understand the Experiment and how to complete the table. As Beaudi proposes ideas and answers, their collaborator Jerry continues to ask clarifying questions, illustrating the category of opening up the problem space and identifying additional uncertainties about the topic. This dialog showcases their uncertainty about the *Learning environment* and *Course content*. Through continuous conversation and collaborative effort, the group progressively resolves their uncertainties. Both group members share their uncertainties and ask each other for information to be able to step by step fill out the observation table and understand the meaning of each variable that can be used for the experiment. Despite both group members occasionally expressing doubt and uncertainty both show effort to resolve those by trying to find a solution and engage in collaboration, consequently, reaching consensus and making a joint decision to move to the next Inquiry phase.

Conclusion Inquiry phase (Conclusion Section)

The uncertainty in the next episode was sparked by the Conclusion inquiry phase where the students compare their established results to their original group prediction.

Episode 14.

Ben: What was our group Prediction?

Sunny: Uh,

idk.

Ben: Crap, man.

Uhmmm.

Sunny: Ah, too bad.

No idea.

I don’t want to ask her either.

Ben: Yeah, same.

Prediction:

"The climate will continue to deteriorate if we don’t take action."

Something like that?

Idk.

Sunny: What a great Prediction.

Ben: Yeah, right?

Sunny: Totally fine.

The group members are uncertain about what the prediction entailed and after expressing their shared uncertainty they agree not to consult their teacher. Nevertheless, they opt for a trial and error experimentation trying to find a prediction that is approved by both group members. Ben proposed a prediction that is met with enthusiasm by Sunny. Sunny encourages him and assures him it looks good. Through trial and error experimentation, and the process of seeking consensus and confirmation, the group effectively resolves their uncertainty related to the *Course content* by employing a strategy of reducing uncertainty. In the textual chat file there is no example of students using *Ignore, Maintain or Increase* as a uncertainty management strategy during the inquiry phase of conclusion.

Discussion

This study explored the types of uncertainties students encounter during inquiry-based learning and the strategies they employ to manage them. By examining how learners experience and respond to uncertainty across the different inquiry phases, we aimed to gain deeper insights into how uncertainty can be harnessed as a productive part of learning, rather than viewed as a barrier. To interpret the findings of this exploratory research, we address each research question individually, connect the results to relevant theoretical background, and draw out practical implications for instructional design and collaborative inquiry environments.

RQ1: *What types of uncertainties do students encounter during inquiry learning?*

In the current study we investigated what types of uncertainties students encounter during the inquiry learning process. We found that the current students' uncertainties attributed to the Course content, Learning environment, Task assignment and Interpersonal relationships. This aligns with Jordan's (2010) proposed types of uncertainties that students face in collaborative learning and emphasizes that uncertainty is a multi-faceted experience, influenced by both cognitive and social aspects of learning. Experiencing such uncertainties reflects Piaget's (1952, 1972) concept of cognitive disequilibrium, where students become aware of gaps between what they know and what the situation demands, triggering opportunities for cognitive restructuring and deeper engagement.

Importantly, we found that the prevalence and nature of students' uncertainties shifted across inquiry phases. For example, during the Investigation phase, the introduction of a drag-and-drop tool appeared to increase learning environment-related uncertainties. This likely stemmed from the cognitive demands associated with mastering a new interface while simultaneously applying conceptual knowledge - an example of extraneous cognitive load (Sweller, 1994). From a practical perspective, this suggests that tools and interfaces could be introduced gradually with explicit guidance, particularly at cognitively demanding phases of inquiry, to prevent unnecessary confusion and disengagement.

In the Orientation phase, students reported heightened uncertainties about task assignment and interpersonal relationships, consistent with the initial "forming" stage of Tuckman’s (1965) group development model. During this time, students were still establishing social norms and figuring out how to collaborate effectively. Such early-stage uncertainties may also reflect socio-cognitive conflict (Mugny & Doise, 1978), where diverging perspectives among peers can catalyse deeper negotiation and mutual understanding. These dynamics underline the importance of providing early scaffolding for group roles and collaboration protocols to reduce ambiguity and facilitate smoother group formation.

As students progressed, uncertainty about course content emerged when confronting new disciplinary concepts. However, this uncertainty diminished as learners likely gained more understanding and confidence. This phase-specific pattern of uncertainty suggests that teachers and designers should anticipate fluctuations in uncertainty levels and be prepared to offer targeted support at specific points in the inquiry cycle - particularly when new tools or content are introduced. During the Conceptualization and Investigation phases, uncertainties again shifted. As students began to form hypotheses and work with newly introduced digital tools, their uncertainties transitioned from course content to learning environment and collaboration focused. The act of aligning hypotheses with tool functionalities, possibly under time constraints or affected by the technical difficulties, may have amplified these challenges. Here, designers could align tool complexity with students’ current cognitive and collaborative readiness, or provide support like examples or prompts.

In the Conclusion process, uncertainties had significantly decreased. Students were now consolidating knowledge and applying previously learned concepts, rather than engaging with novel material (McClelland et al., 2020). Uncertainties around collaboration and task division had also diminished, likely because expectations and roles had already been negotiated. Other reasons why uncertainty was not observed in the chat conversation could be due to external factors such as time pressure, technical challenges e.g. internet issues, or limited motivation, including reluctance to use the chat feature. This highlights the desire to design inquiry environments that minimize technical friction and encourage active communication, even in later stages. Taken together, these findings suggest that uncertainty is not static but evolves throughout the inquiry process. Such evolution supports a developmental view of learning, in which phases of disequilibrium fosters deeper understanding (Piaget, 1972). Educators should anticipate phase-dependent uncertainties, provide targeted support, and encourage students to normalize uncertainty as a productive part of the learning experience.

RQ2: *How do students manage uncertainties during inquiry learning?*

The current study shows that students primarily used the Reduce strategy to manage uncertainty, although Ignore, Maintain, and Increase strategies were also observed. These findings align with Jordan’s (2010) research on uncertainty management strategies in collaborative settings and demonstrate that students adaptively shift between strategies based on context. This indicates that learners do not rely on one fixed strategy but instead apply a range of different uncertainty management strategies. Some students reduced uncertainty by asking peers or seeking confirmation from instructors, while others maintained or even increased uncertainty to explore multiple perspectives before making a decision. These findings support the view that uncertainty must not be eliminated; rather, different strategies serve different cognitive and social functions depending on the learning phase and context (Babrow et al., 1998; Weick, 1995).

At the start of the inquiry process, students largely relied on the Reduce strategy, actively seeking clarification and confirmation from peers. This early engagement might be due to the manageable nature of initial tasks, which emphasized prior knowledge and familiar content. The presence of minimal ambiguity at this stage supports Poli et al.’s (2022) argument that extreme uncertainty tends to prompt avoidance or deferral, while moderate uncertainty invites active engagement. As the inquiry progressed and the structure of the Eco-Lab became more familiar, students increasingly used the Maintain strategy, choosing to delay resolving certain uncertainties. This behaviour may reflect a growing metacognitive awareness of which uncertainties were critical and which could be postponed - a skill associated with strategic regulation in self-directed learning (Efklides, 2006). This awareness is part of self-regulated learning, where learners monitor and adjust their engagement with uncertainty in real time. This suggests that educators can encourage students to recognize and evaluate their uncertainties, possibly through reflective prompts embedded at transition points in the inquiry process.

The collaborative features of the Eco-Lab, particularly the chat function, played a crucial role in how students managed uncertainty. The chat enabled students to share questions, clarify roles, and seek peer feedback, supporting the Reduce strategy in a social context. However, in cases where peers failed to respond or provided inadequate help, some students responded with frustration or disengagement, leading to the use of the Ignore or Maintain strategies (see Episode 11). These moments underscore the value of teaching productive collaboration skills for uncertainty management, such as framing helpful questions or respectfully challenging a peer's idea, as proposed by Kaur and Dasgupta (2024). Students' ability to navigate uncertainty collaboratively also resonates with theories of socio-cognitive conflict (Mugny and Doise, 1978), where peer interaction plays a central role in managing and resolving conflicting ideas. Designers can foster more effective communication by making peer contributions more visible or adding feedback mechanisms that ensure accountability.

In the investigation process, where unfamiliar tools were introduced, uncertainty levels increased. This seemed to correspond with a rise in Ignore and Maintain strategies, as students may have felt overwhelmed by both cognitive and collaborative demands. In line with Poli et al. (2022), such extreme uncertainty can lead to withdrawal (see Episode 11) or blame (see Episode 12), particularly if students lack confidence or feel unsupported. This highlights the desire for designs that support both cognitive scaffolding and emotional resilience, such as allowing undo actions, offering problem-solving guidance, or building supportive peer norms. By the conclusion phase, students returned to the Reduce strategy. As they synthesized their findings and evaluated predictions, many sought consensus with peers - behaviour that aligns with the desire to achieve cognitive closure (Johnson and Johnson, 2009). This was a natural ending point where students resolved remaining uncertainties and finalized group understanding. Instructionally, this phase could be enhanced by encouraging reflective activities, prompting students to articulate what uncertainties were resolved and what questions remain.

Interestingly, the use of the Increase strategy, where students deliberately explore or expand uncertainty, was rare. This may indicate a missed opportunity for deeper inquiry and exploration, suggesting that tasks could have been more open-ended or framed to encourage generative thinking. As Limón (2001) and Potvin (2023) argue, productive uncertainty often stems from cognitive conflict and open-ended challenges, that invite learners to engage in deeper learning strategies, such as elaboration, self-explanation, and metacognitive reflection (Eysink and de Jong, 2012; D'Mello and colleagues, 2014). Inquiry-based learning tasks that encourage group discussion and creative exploration, might naturally incline students to share new ideas and expand on their experienced uncertainties. Educators and developers could consider including structured opportunities for creative risk-taking, such as asking students to propose alternative explanations or design additional experiments.

This study highlights that uncertainty during inquiry learning is dynamic, context-dependent, and shaped by both individual cognition and group interactions. Environments that encourage and guide students to manage their uncertainties productively provide valuable learning opportunities. This would help students feel more confident during challenging learning situations and increase their learning potential. Managing uncertainty is a relevant skill that can enhance students' self-regulation and problem-solving in complex real-world situations (Rosen, 2019). Inquiry learning environments should, therefore, be designed to guide students toward managing their uncertainty autonomously in the future.

Conclusion

Implications for Educational Design

In education, understanding uncertainty is essential for both teachers and students. By recognizing the dynamics of the inquiry process, considering its specific context and the challenges students encounter, teachers can design learning environments that offer appropriate support and guidance, addressing students' needs accordingly. The inquiry process of investigation has been shown to induce greater moments of uncertainty. Taking this into account when designing experimental tasks is valuable to promote productive uncertainty management and not induce extreme forms of uncertainty as proposed by Poli et al. (2022). Given these challenges, it is crucial to provide appropriate guidance throughout the individual phases of the Inquiry learning cycle. This includes timely intervention and relevant probing to guide uncertain conversations in a focused direction and foster a supportive environment that encourages students to express uncertainties to peers or teachers, as Kaur and Dasgupta (2024) mentioned.

The results support Kaur and Dasgupta's studies on peer learning and social regulation of learning (2024), emphasizing the influence of peer responses in managing uncertainty in collaborative settings. When uncertainty is acknowledged and addressed collaboratively, students are more likely to resolve uncertainty through explanation and discussion (Jordan, 2010, Kaur and Dasgupta, 2024). Conversely, when uncertainty is dismissed or ignored by their group member, students may disengage or adopt a similar uncertainty management strategy. Therefore, the current research underscores the importance of peer response, highlighting the role of supportive group collaboration in helping students successfully navigate uncertainties in Inquiry-based learning environments. Highlighting the amount of uncertainty episodes displayed in this study, the current research adds to the notion that uncertainty is a natural and valuable part of learning, especially in inquiry-based learning environments. By examining how the different inquiry phases relate to uncertainty, educators can create learning experiences that encourage curiosity, critical thinking, and resilience in the face of ambiguity, using uncertainty as a powerful learning tool. Teachers can encourage productive uncertainty by helping students examine their existing knowledge, identify contradictions, and explore possible solutions. To support this, educators can inspire the following instructional strategies (Chen, 2024).

1. *Increase* uncertainty to motivate students to question and expand their knowledge.
2. *Maintain* or *Ignore* uncertainty to promote deeper understanding and a search for consensus.
3. *Reduce* uncertainty to make progress with the learning task.

This process strengthens the development of their scientific knowledge and helps students navigate uncertainty (Chen, 2024). As mentioned previously, engaging in open-ended, inquiry-based activities builds students' confidence in handling uncertainty, an essential skill that creates value beyond the classroom (Youngerman and Culver, 2019; Rosen, 2019). According to Chen (2024), effectively managing uncertainty involves encouraging students to perceive it as an opportunity for exploration rather than a challenge to avoid. It helps the students view uncertainty as an opportunity for inquiry rather than a barrier in their way. Thus, integrating inquiry-based learning into the curriculum might already set up a valuable environment to encourage productive uncertainty management. The current Inquiry-based learning environment highlights the value of designing and constructing supportive learning environments that make students feel more capable of managing their uncertainties through the encouragement of uncertainty expression (Chen, 2024). Encouraging the expression of uncertainty helps students feel more inclined to voice their doubts and seek deeper understanding. Creating an environment where uncertainty is expected and valued can help learners feel more comfortable expressing doubts. Teachers or educational agents can guide learners in expressing their uncertainties, building connections, and establishing arguments. Encouraging students to write about their doubts and how they approach uncertainty can further support this process.

The inquiry learning cycle presents students with ambiguous, real-life scenarios, such as climate change solutions or historical interpretations, demonstrating that uncertainty can be productively managed in multiple ways. It encourages students to explore different perspectives and develop problem-solving skills (Rosen, 2019), and, further, to ask insightful, open-ended questions instead of focusing on finding solely correct answers. To cultivate this active participation, we confirm Chen’s (2024) claim to encourage educators to develop inquiry learning systems that empower students to embrace uncertainty and investigate the gaps in their knowledge. This approach supports students’ ability to manage uncertainty effectively while fostering a more collaborative dynamic between learners and teachers (Kaur and Dasgupta, 2024). Ultimately, facilitating Inquiry-based learning in the learning environment can be useful in teaching students how to navigate uncertainty productively.

Strengths, Limitations, and Future Research

Through the discussion, we found that beyond understanding learners’ uncertainty management in inquiry-based learning, the inquiry-based learning environment presents an instructional tool that can naturally encourage students’ uncertainty expression. The findings underscore the potential for educational interventions and the design of Inquiry Learning Spaces (ILSs) to enhance productive uncertainty management. In educational contexts, which increasingly emphasize inquiry-based learning approaches and encourage students to engage in discussions and explore diverse perspectives and solutions, it is important to understand and foster productive uncertainty management, particularly within collaborative environments. The current study conducted exploratory research on uncertainty management of Dutch secondary school students within an online Inquiry Learning Space, exploring their uncertainty management and types of uncertainties in inquiry learning environments. It would be valuable for future studies to investigate the influence of uncertainty management on the quality of these inquiry processes and student outcomes.

Future research could also look into whether the current findings hold in other inquiry scenarios. We found different uncertainty management strategies in different phases of the inquiry cycle. This could include future research on uncertainty management across different educational platforms, such as other ILSs within or outside Go-Lab and inquiry learning systems, and other subject areas outside of climate change. Further research is valuable to see if the results of the current study hold with different age groups and how uncertainty management strategies evolve over multiple learning sessions which could provide deeper insights into the factors contributing to students' selection of strategies.

In the current study, the students were instructed to solely communicate with their peer collaborators via the chat box. Through the direct communication tool of the chat box, the students had the opportunity to communicate, discuss, and reflect on their experienced uncertainty with their peer collaborators throughout the Eco-Lab. This aligns with the research of De Jong and Njoo (1992), where this process showed support for meta-cognition and regulative processes of inquiry learning, and gives insights into how students communicate their experienced uncertainties during the inquiry learning process. While the chat tool enabled the students to express their thoughts and ideas, it might have still limited their communication channels. The students might not have written down their experienced uncertainties, especially when they chose to ignore their uncertainty, therefore, not acknowledging their uncertainties to begin with. The chat box, likewise, naturally does not include paralinguistic markers of uncertainty which would add more insights into uncertainty expression. Future research addressing this limitation will be useful to explore student uncertainty expression during inquiry learning through different communication tools.

To deepen the understanding of uncertainty management in all phases of the inquiry process, incorporating a focused section in the ILS for the reflection subphase of the discussion process could provide students with a dedicated space to reflect and analyse their learning progress. This section would allow them to assess their experiences in each inquiry phase and reflect on their collaborative efforts, reinforcing the key learning objectives of the Inquiry cycle.

Conclusion

The current study aimed to explore the connection between uncertainty management and inquiry-based learning environments. Concludingly, the current research reveals that students engage in various uncertainty management strategies throughout the inquiry learning cycle and what types of uncertainties they experience varying throughout the inquiry process. By deepening the understanding of learners' uncertainty management processes, this study contributes valuable insights into how students navigate and respond to uncertainty during inquiry-based learning. This study explores the importance of uncertainty management in inquiry-based learning, emphasizing the role of peer collaboration and the value of designing learning environments that encourage productive uncertainty management. It highlights the idea that increasing uncertainty can serve as a tool to foster deeper learning and encourage productive collaboration among students. The study builds on previous research that focuses on designing learning environments that actively encourage exploration and uncertainty to create deep-learning opportunities for the students and underscores the implementation of inquiry learning opportunities for productive uncertainty management (Feng, 2024).

To conclude, our study confirms previous claims (e.g., Chen, 2024; Rosen, 2019) that educational systems often fail to nurture students' tolerance for ambiguity. The pressure for efficiency and correct answers may discourage exploration, thereby preventing students from developing resilience in the face of complex, uncertain problems. By supporting students in learning how to manage uncertainty - especially through productive collaborative dialogue and guided inquiry - we can move closer to educational environments that foster adaptive thinking, creativity, and lifelong learning.

References

Addyman C., and Mareschal D. (2013). Local redundancy governs infants' spontaneous orienting to visual-temporal sequences. *Child Development, 84*(4), 1137–1144.

Almakky, H. (2023). Analyzing the Behavior of Individuals with High Uncertainty Avoidance in Relation to the Design of online Game-Based Educational Learning Interfaces. *Journal of Positive Psychology & Wellbeing*, 7(3), 348-370. Education Technology, King Abdulaziz University: Saudi Arabia.

Anderson, L. W. (2003). *Classroom assessment: Enhancing the quality of teacher decision making*. Lawrence Erlbaum Associates Publishers.

Arthur, W. B. (1999). Complexity and the economy. *Science, 284*(5411), 107-109.

Babrow, A. S., Hines, S. C., and Kasch, C. R. (1998). Managing uncertainty in illness explanation: An application of problematic integration theory. *Health Communication, 10*(1), 1–23.

Baker, M., Järvelä, S., and Andriessen, J. (2013). Affective Learning Together: social and emotional dimensions of collaborative learning. Routledge.

Baker, R. S., D'Mello, S. K., Rodrigo, M. T., and Graesser, A. C. (2010). Better to be frustrated than bored: The incidence and persistence of affect during interactions with three different computer-based learning environments. *International Journal of Human-Computer Studies, 68*, 223– 241.

Baranes A. F., Oudeyer P. Y., and Gottlieb J. (2014). The effects of task difficulty, novelty and the size of the search space on intrinsically motivated exploration. *Frontiers in Neuroscience, 8*, 317.

Bereiter, C., and Scardamalia, M. (1993). Surpassing ourselves: An inquiry into the nature and implications of expertise. La Salle, IL: Open Court.

Bonnet, A., and Glazier, J. (2023). The conflicted role of uncertainty in teaching and teacher education. *Teachers and Teaching, 31*(2), 201–217.

Chen, Y. C. (2024). Cultivating a higher level of student agency in collective discussion: teacher strategies to navigate student scientific uncertainty to develop a trajectory of sensemaking. *International Journal of Science Education*, 1-34.

Chu, S. K. W., Reynolds, R. B., Tavares, N. J., Notari, M., and Lee, C. W. Y. (2021). 21st century skills development through inquiry-based learning. From theory to practice. *Springer International Publishing*.

Clark A. (2013). Whatever next? Predictive brains, situated agents, and the future of cognitive science. *Behavioral and Brain Sciences, 36*(3), 181–204.

Craig, S.D., Graesser, A.C., Sullins, J. and Gholson, B. (2004). Affect and learning: an exploratory look into the role of affect in learning. *Journal of Educational Media, 29*, 241–250.

de Jong, T., Lazonder, A. W., Chinn, C. A., Fischer, F., Gobert, J., Hmelo-Silver, C. E., Koedinger, K. R., Krajcik, J. S., Kyza, E. A., Linn, M. C., Pedaste, M., Scheiter, K., and Zacharia, Z. C. (2023). Let’s talk evidence – the case for combining inquiry-based and direct instruction. *Educational Research Review, 39*(100536).

de Jong, T. (2019). Moving towards engaged learning in STEM domains; there is no simple answer, but clearly a road ahead. *Journal of computer assisted learning, 35*(2), 153-167.

de Jong, T., and Njoo, M. (1992). Learning and instruction with computer simulations : learning processes involved. In Computer-based learning environments and problem solving / eds. E. De Corte; M. Linn; H. Mandl; L. Verschaffel (pp. 411-429). Springer.

Deslauriers, L., McCarty, L., Miller, K., Callaghan, K., and Kestin, G. (2019). Measuring actual learning versus feeling of learning in response to being actively engaged in the classroom. *Proceedings of the National Academy of Sciences. 116*.

Dewey, J. (1933). *How We Think: A Restatement of the Relation of Reflective Thinking to the Educative Process*. Boston, MA: D.C. Heath & Co Publishers.

D'Mello, S., Lehman, B., Pekrun, R., and Graesser, A. (2014). Confusion can be beneficial for learning. *Learning and Instruction, 29,* 153–170.

Efklides, A. (2006). Metacognition and affect: What can metacognitive experiences tell us about the learning process? *Educational Research Review, 1,* 3-14.

Engle, R. A. (2011). The productive disciplinary engagement framework: Origins, key concepts, and developments. In D. Dai (Ed.), *Design research on learning and thinking in educational settings: Enhancing growth and functioning.* New York, NY: Routledge.

Engle, R. A., and Conant, F. R. (2002). Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a community of learners classroom. *Cognition and Instruction, 20(*4), 399–483.

Eysink, T. H. S., and de Jong, T. (2012). Does Instructional Approach Matter? How Elaboration Plays a Crucial Role in Multimedia Learning. *The Journal of the Learning Sciences, 21*(4), 583–625.

Faisal, C. M. N., Gonzalez-Rodriguez, M., Fernandez-Lanvin, D., and De Andres-Suarez, J. (2017). Web Design Attributes in Building User Trust, Satisfaction, and Loyalty for a High Uncertainty Avoidance Culture. *IEEE Transactions on Human-Machine Systems, 47*(6), 847-859.

Feichtner, S. B., and Davis, E. A. (2016). Republication of “Why some groups fail: A survey of students’ experiences with learning groups”. *Journal of Management Education*, *40*(1), 12-29.

Feng, X., Wang, X., Huo, Y., and Luo, Y. (2024). Inquiry in uncertainty-nursing students' learning experience in challenge-based learning: A qualitative study. *Nurse Education Today, 135*.

Festinger, L. (1957). A theory of cognitive dissonance. Stanford University Press.

Fitzgibbon, L., and Murayama, K. (2022). Counterfactual curiosity: Motivated thinking about what might have been. *Philosophical Transactions of the Royal Society B, 377*(1866).

Glanville, R. (2007). Try again. Fail again. Fail better: The cybernetics in design and the design in cybernetics. *Kybernetes*, *36*(9/10), 1173–1206.

Giddens, A. (1990). *The Consequences of Modernity*. Cambridge: Polity Press.

Harlen, W. (2013). *Assessment & inquiry-based science education: Issues in policy and practice.* Global Network of Science Academies.

Hofstede, G. (2001). *Culture’s Consequences: Comparing Values, Behaviors, Institutions, and Organizations Across Nations*. 2nd ed. Newbury Park, CA, USA: Sage.

Ison, R. L., Collins, K. B. and B. L. Iaquinto, B. L. (2021). Designing an Inquiry-Based Learning System: Innovating in Research Praxis to Transform Science-Policy-Practice Relations for Sustainable Development. *Systems Research & Behavioural Science, 38*(5), 610–624. Crossref. Web of Science.

Samson, D. W., and Samson, R. T. (2009). An educational psychology success story: Social interdependence theory and cooperative learning. *Educational Researcher, 38*(5), 365–379.

Jordan, M. (2010). *Managing Uncertainty in Collaborative Robotics Engineering Projects: The Influence of Task Structure and Peer Interaction*. Doctoral dissertation.

Jordan, M. E., and McDaniel Jr., R. R. (2014). Managing Uncertainty During Collaborative Problem Solving in Elementary School Teams: The Role of Peer Influence in Robotics Engineering Activity. *Journal of the Learning Sciences, 23*(4), 490-536.

Kahneman, D., and Tversky, A. (1982). The psychology of preferences. *Scientific American, 246*(1), 160–173.

Kaur, N., and Dasgupta, C. (2024). Investigating the interplay of epistemological and positional framing during collaborative uncertainty management. *Journal of the Learning Sciences*, *33*(1), 80–124.

Keselman, A. (2003). Supporting inquiry learning by promoting normative understanding of multivariable causality. *Journal of Research in Science Teaching, 40*, 898-921.

Kilduff, M., Angelmar, R., and Mehra, A. (2000). Top management-team diversity and firm performance: Examining the role of cognitions. *Organization Science, 11*(1), 21–34.

Kruglanski, A. W., and Webster, D. M. (1996). Motivated closing of the mind: "Seizing" and "freezing." *Psychological Review, 103*(2), 263–283.

Lamnina, M., and Chase, C. C. (2019). Developing a thirst for knowledge: How uncertainty in the classroom influences curiosity, affect, learning, and transfer. *Contemporary Educational Psychology*, 59(101785).

Lee, G., and Byun, T. (2011). An explanation for the difficulty of leading conceptual change using a counterintuitive demonstration: the relationship between cognitive conflict and responses. Research in Science Education, 1-23.

Lehrer, R. (2009). Designing to develop disciplinary dispositions: Modeling natural systems. *American Psychologist, 64*(8), 759–771.

Limón, M. (2001). On the cognitive conflict as an instructional strategy for conceptual change: A critical appraisal. *Learning and Instruction, 11*(4–5), 357-380

Lipshitz, R., and Strauss, O. (1997). Coping with Uncertainty: A Naturalistic Decision-Making Analysis. *Organizational Behavior and Human Decision Processes, 69*, 149-163.

Liquin, E. G., Callaway, F., and Lombrozo, T. (2021). Developmental change in what elicits curiosity. *Proceedings of the Annual Meeting of the Cognitive Science Society*, *43*(43).

Loes, C. N., and Pascarella, E. T. (2017). Collaborative Learning and Critical Thinking: Testing the Link. *The Journal of Higher Education, 88*(5).

Manz, E., and Suárez, E. (2018). Supporting teachers to negotiate uncertainty for science, students, and teaching. *Science Education, 102*(4), 771–795.

Marcus, A. (2000). Cultural dimensions and global web UI design. *White Paper,* 1–27.

McClelland, J. L., McNaughton, B. L., and Lampinen, A. K. (2020). Integration of new information in memory: new insights from a complementary learning systems perspective. Philosophical transactions of the Royal Society of London. Series B. *Biological sciences*, *375*(1799).

McDaniel, M. A., Hartman, N. S., and Grubb III, W. L. (2003, April). *Situational judgment tests, knowledge, behavioral tendency, and validity: A meta-analysis.* Paper presented at the 18th Annual Conference of the Society for Industrial and Organizational Psychology. Orlando.

McKnight, D. H., Choudhury, V., and Kacmar, C. (2002). Developing and validating trust measures for e-commerce: An integrative typology. *Inf. Syst. Res., 13*, 334–359.

Metz, K. E. (2004). Children's understanding of scientific inquiry: Their conceptualization of uncertainty in investigations of their own design. *Cognition and Instruction, 22*(2), 219–290.

Mugny, G., Levy, M., and Doise, W. (1978). Socio-cognitive conflict and cognitive development. *Schweizerische Zeitschrift für Psychologie und ihre Anwendungen / Revue suisse de Psychologie pure et appliquée, 37*(1), 22–43.

Näykki, P., Järvenoja, H., Järvelä, S. and Kirschner, P. (2015). Monitoring makes a difference: quality and temporal variation in teacher education students' collaborative learning. *Scandinavian Journal of Educational Research*, 1–16.

O'Donnell, A. M. (2006). The role of peers and group learning. In P. A. Alexander and P. H. Winne (Eds.), Handbook of educational psychology (2nd ed., pp. 781–802). Mahwah, NJ: Erlbaum.

Pedaste, M., Mäeots, M., Siiman, L., De Jong, T., van Riesen, S., and Kamp, E. (2015). Phases of inquiry-based learning: Definitions and the inquiry cycle. *Educational Research Review*, *14*, 47-61.

Pekrun, R., Goetz, T., Titz, W., and Perry, R. P. (2002). Academic emotions in students' self-regulated learning and achievement: A program of qualitative and quantitative research. *Educational Psychologist, 37*(2), 91–105.

Piaget, J. (1972). Intellectual evolution from adolescence to adulthood. *Human Development, 15*(1), 1–12.

Piaget, J., and Cook, M. (1952). The origins of intelligence in children International Universities Press, New York.

Potvin, P. (2023). Response of science learners to contradicting information: A review of research. *Studies in Science Education, 59*(1), 67-108.

Poli, F., Meyer, M., Mars, R. B., and Hunnius, S. (2022). Contributions of expected learning progress and perceptual novelty to curiosity-driven exploration. *Cognition, 225*.

Poli F., Serino G., Mars R.B., and Hunnius S. (2020). Infants tailor their attention to maximize learning. *Science Advances, 6*(39), 5053–5076.

Potvin, P., and Cyr, G. (2017). Toward a durable prevalence of scientific conceptions: Tracking the effects of two interfering misconceptions about buoyancy from preschoolers to science teachers. *Journal of Research in Science Teaching, 54*, 1121-1142.

Reiser, B. J. (2004). Scaffolding Complex Learning: The Mechanisms of Structuring and Problematizing Student Work. *Journal of the Learning Sciences*, *13*(3), 273–304.

Riah, H., and Fraser, B. J. (1998, April). Chemistry learning environment and its association with students' achievement in chemistry. In annual meeting of the American Educational Research Association, San Diego, CA.

Rosen, Diane (2019). Being in Uncertainties: An Inquiry-based Model Leveraging Complexity in Teaching-Learning. *Northeast Journal of Complex Systems (NEJCS), 1*(5).

Sanchez, T., Caramiaux, B., Thiel, P., and Mackay, W. E. (2022). Deep Learning Uncertainty in Machine Teaching. In 27th International Conference on Intelligent User Interfaces (IUI '22), March 22–25, 2022, Helsinki, Finland. ACM, New York, NY, USA, 18 pages.

Scanlon, E., Anastopoulou, S., Kerawalla, L., and Mulholland, P. (2011). How technology resources can be used to represent personal inquiry and support students' understanding of it across contexts. *Journal of Computer Assisted Learning, 27*, 516-529.

Smithson, M. (1989). *Ignorance and uncertainty: Emerging paradigms*. Springer-Verlag Publishing.

Sorrentino, R. M., and Roney, C. J. R. (2000). *The uncertain mind: Individual differences in facing the unknown*. Psychology Press.

Springer, L., Stanne, M. E., and Donovan, S. S. (1999). Effects of Small-Group Learning on

Undergraduates in Science, Mathematics, Engineering and Technology: A Meta-Analysis. *Review of Educational Research, 69*(1), 21–52.

Strijbos, J. W., Martens, R., Prins, F., and Jochems, W. (2006). Content analysis: What are they talking about? *Computers and Education, 46*, 29-48.

Sweller, J. (1994). Cognitive load theory, learning difficulty, and instructional design. *Learning and Instruction, 4*(4), 295–312.

Terenzini P. T., Cabrera A. F., Colbeck C. L., Parente J. M., Bjorklund S. A. (2001). Collaborative learning vs. lecture/discussion: Students' reported learning gains. *Journal of Engineering Education, 90*(1), 123–130.

Tuckman, B. W. (1965). Developmental sequence in small groups. *Psychological Bulletin*, *63*(6), 384–399.

van Lieshout, L. L. F., de Lange, F. P., and Cools, R. (2021). Uncertainty increases curiosity, but decreases happiness. *Scientific Reports, 11*(1).

van Joolingen, W.R., Zacharia, Z.C. (2009). Developments in Inquiry Learning. In: Balacheff, N., Ludvigsen, S., de Jong, T., Lazonder, A., and Barnes, S. (eds) Technology-Enhanced Learning. Springer, Dordrecht.

van Joolingen, W. R. and de Jong, T. (1991). Supporting hypothesis generation by learners exploring an interactive computer simulation. *Instructional Science, 20*, 389-404.

Watkins, L. E., Sprang, K. R., and Rothbaum, B. O. (2018). Treating PTSD: A Review of Evidence-Based Psychotherapy Interventions. Frontiers in behavioral neuroscience, 12, 258.

Weick, K. E. (1995). *Sensemaking in Organizations*. Sage Publications.

Youngerman, E. and Culver, K. (2019). Problem-Based Learning (PBL): Real-World Applications to Foster (Inter)Disciplinary Learning and Integration. *New Directions for Higher Education*, 23-32.

AI Statement:

During the preparation of this work I used Chat GPT in order to improve the readability and language of my work. After using this tool, I reviewed and edited the content as needed and take full responsibility for the content of the work.

APPENDIX A

Figure 1

Introduction Section of the Climate Change Eco-Lab

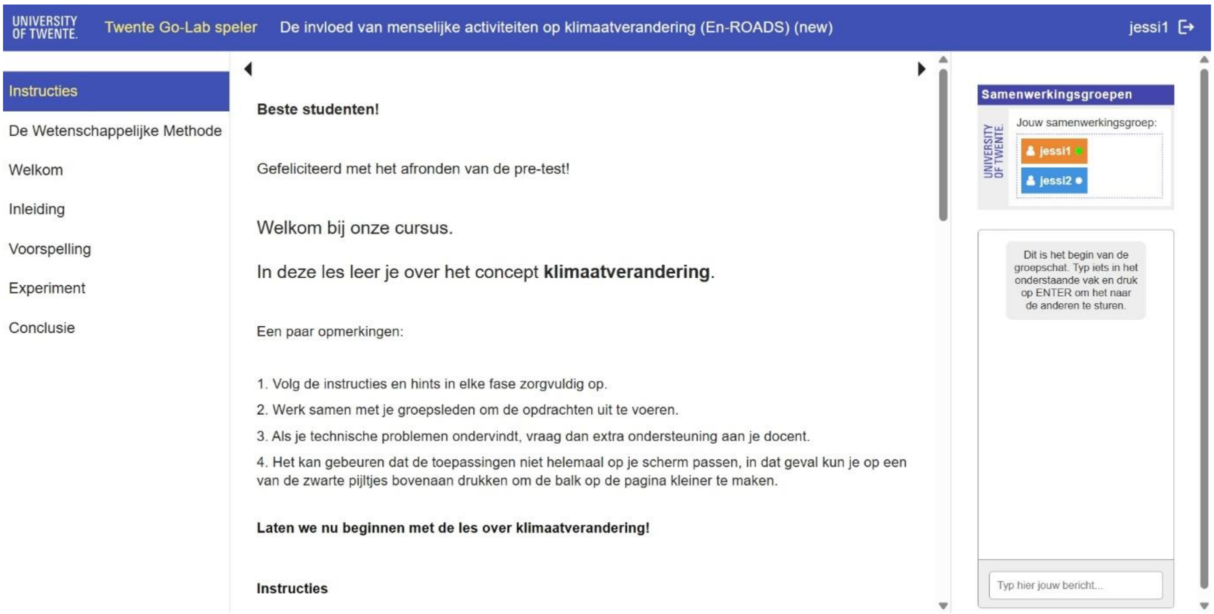


Figure 2

The Scientific Method Section of the Climate Change Eco-Lab

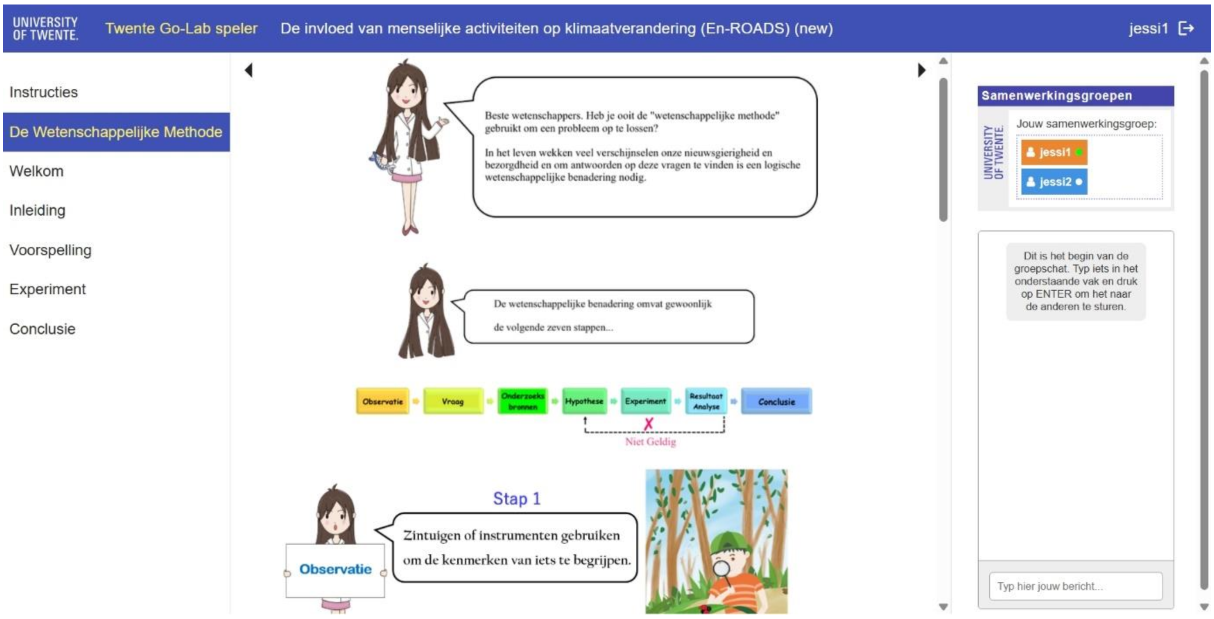


Figure 3

Welcome Section of the Climate Change Eco-Lab

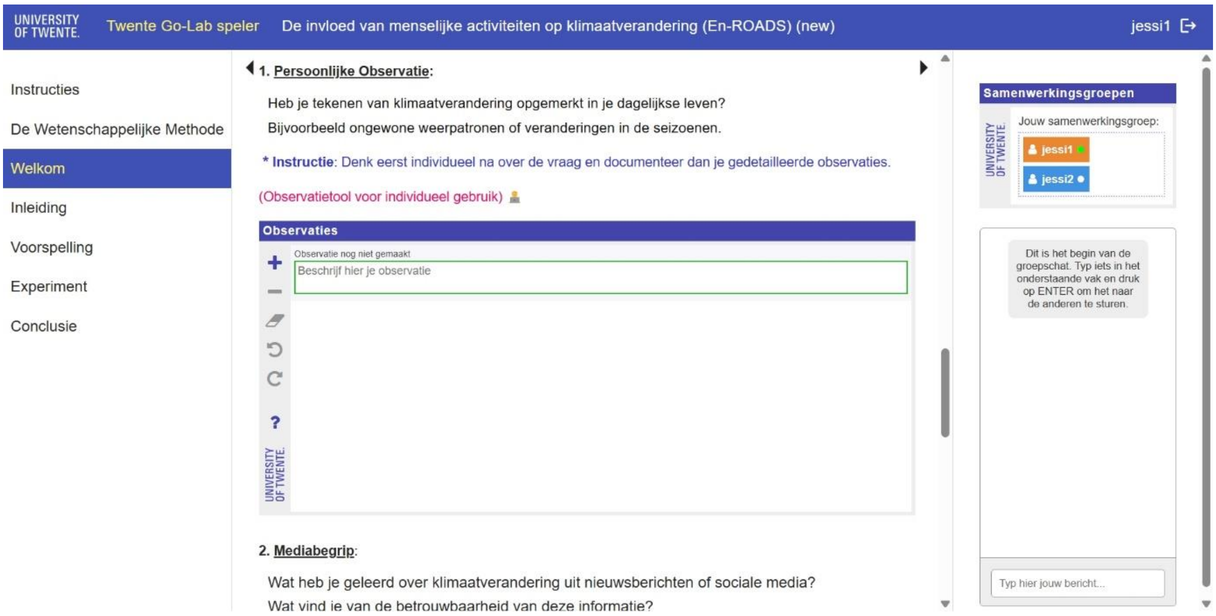


Figure 4

Introduction Section of the Climate Change Eco-Lab

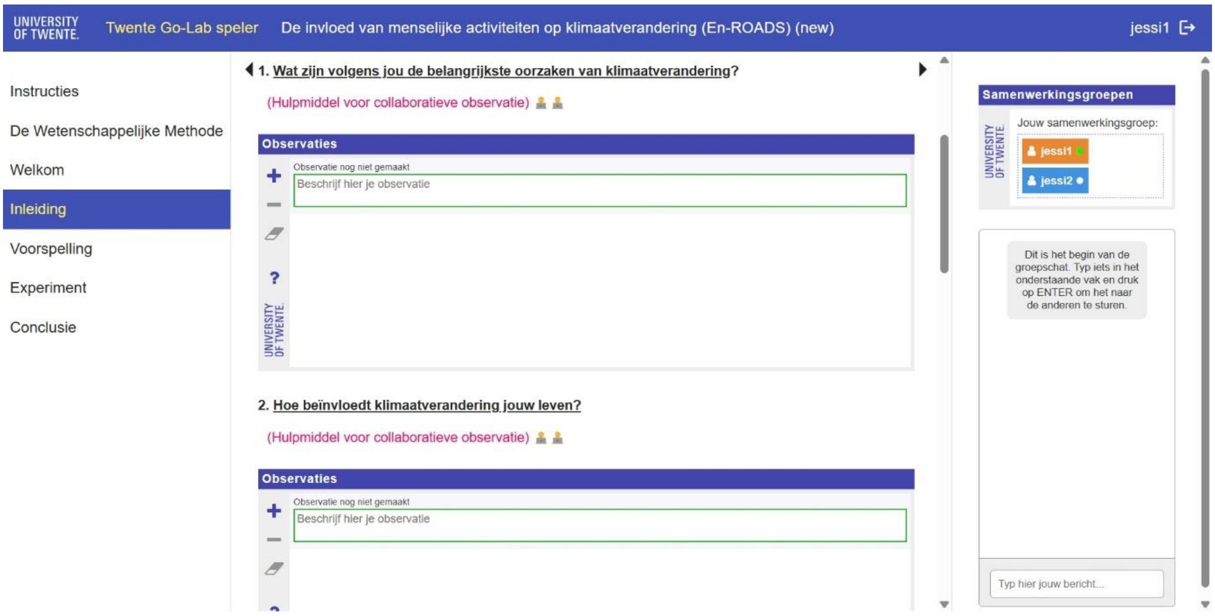


Figure 5

Prediction Section of the Climate Change Eco-Lab

Figure 6

Experiment Section of the Climate Change Eco-Lab

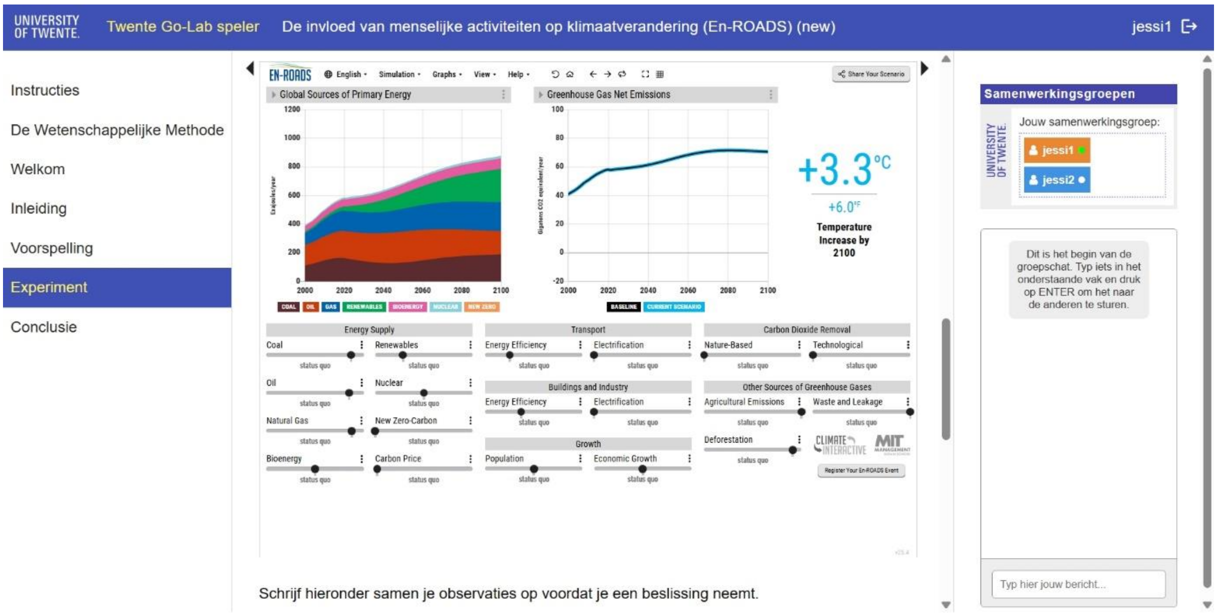


Figure 7

Conclusion Section of the Climate Change Eco-Lab