Managing Uncertainty for Productive Struggle: Exploring Teacher Development for Managing Students' Epistemic Uncertainty as a Pedagogical Resource in Project-Based Learning

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Research Questions

RQ 1: How does **sustained engagement with professional development in uncertainty management** affects **teachers' capacity** to recognize and utilize students' epistemic uncertainty as a **pedagogical resource** for engaging students in productive struggle to develop scientific knowledge?

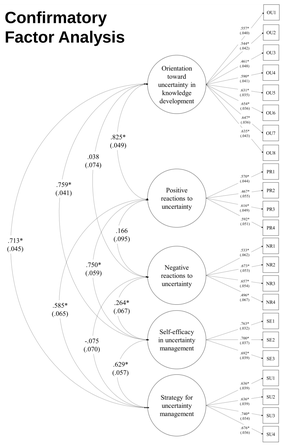
RQ 2: How do teachers' **instructional practice** in managing epistemic uncertainty **change over time** when they utilize epistemic uncertainty as a pedagogical resource for engaging students in productive struggle?

RQ 3: How do teachers' approach to managing uncertainty influence **students' perceptions, practice, and management of epistemic uncertainty**?

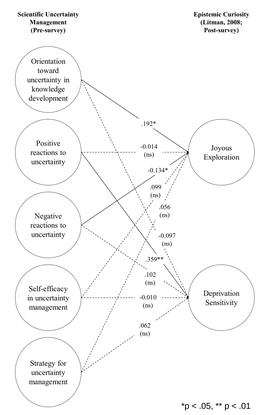
❖ Students from twelve middle-school teacher classrooms

Gender	Grade			Total
	6th	7th	8th	
Male	45	165	242	252
Female	45	124	215	384
Non-binary	1	15	24	40
Total	91	304	481	876

Confirmatory Factor Analysis

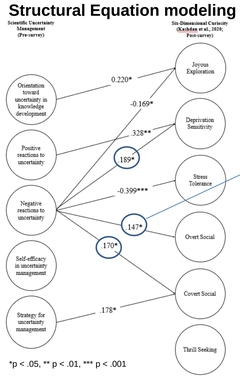


Structural Equation modeling I



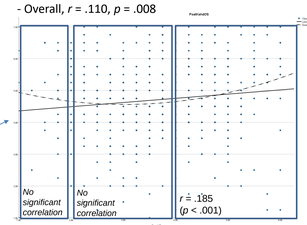
*p < .05, ** p < .01

Structural Equation modeling II



*p < .05, ** p < .01, *** p < .001

Relationship between Negative Reaction to Uncertainty and Overt Social
- Overall, r = .110, p = .008



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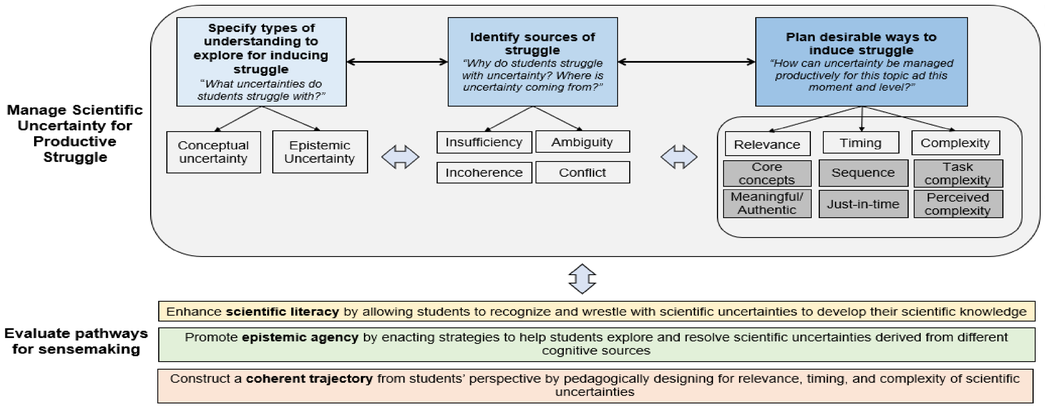
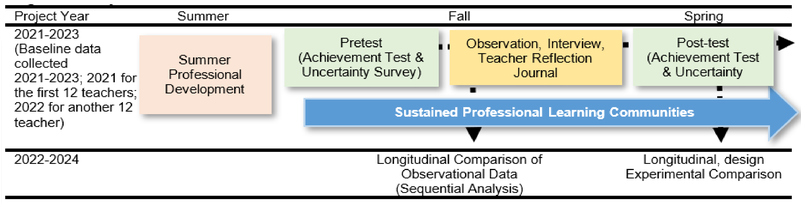
Kashdan, T. B., Disabato, D. J., Goodman, F. R., & McKnight, P. E. (2020). The Five-Dimensional Curiosity Scale Revised (5DCR): Briefe r subscales while separating overt and covert social curiosity. *Person ality and Individual Differences, 157*, 109836.
Litman, J. A. (2008). Interest and deprivation factors of epistemic cu riosity. *Personality and individual differences*, *44*(7), 1585-1595.



❖ Student Uncertainty as a Pedagogical Resource (SUPeR)

Goals to Guide Teachers	Approach	Questions to Guide Students
Phase 1: Problematize a Phenomenon		
1. Explore a phenomenon and identify students' knowledge gaps and curiosities. 2. Frame an uncertainty and develop a plan to address it.		***Knowledge:*** What am I certain about? What am I not certain about? What do I need to know? ***Question:*** What are my questions about the phenomenon?
Classroom Products		
1. Core concepts to explore 2. Variables to explore (e.g., dependent, independent) 3. Researchable and testable/ solvable problems		
Phase 2: Material Practice		
1. Enact a plan to address the uncertainty, collecting and analyzing data 2. Develop intuitions based on interaction with materials		***Design:*** What investigation can I design to address my questions? ***Data:*** What data can I collect? How can I organize my data?
Classroom Products		
1. Investigation/ design procedures/ prototype 2. Data set organized by different modalities (e.g., tables, figures, graphs, diagrams, pictures)		
Phase 3: Argumentative Practice		
1. Interpret data and meaning of the results of testing/experiments, including ambiguous, unexpected, incoherent, or conflict results 2. Generate multiple perspectives, seek convergent understandings		***Solution (individual):*** What evidence do I have to support my claim? How consistent are my results (with my expectations and across the dataset)? ***Comparison (group):*** How do my results and my ideas compare with others? What should I change about my ideas or my science practices? What can I suggest to peers to help improve their investigation/analysis/prototype?
Classroom Products		
1. Collective interpretation/ consensus of the phenomenon 2. Recognize claims, understandings, processes that need clarification		
Phase 4: Reflection, Application, and Transformation		
1. Think systemically, think beyond the system at hand, generalizing knowledge 2. Generating new questions and uncertainties linked to the next unit		*Reflection:* How have my ideas changed on a continuum between uncertainty and certainty? *Relevance:* What can I do with the new knowledge? How do I situate it relative to other things I care about or know? *New uncertainty:* What new questions or uncertainties does this knowledge raise for me? *Transformation:* How do I explain my ideas to different audiences using multiple modes of representation?
Classroom Products		
1. Connection the developed knowledge to theory (conceptually) 2. Application of the developed knowledge to make a prediction in a new situation (practically)		



Teacher pathways to manage uncertainties from observation (RQ2)
Theory-driven combined with data-driven codes

Storylines	0	1	2	3
(Reiser et al., 2021)	There is no lesson plan or pathway observed	Teacher designed a lesson plan involving mostly lectures and/or direct instruction with little time built in for student discovery or exploration	Teacher intentionally designed a lesson integrating prior knowledge but does not dig deeper into the content to identify unanswered questions	Teacher positions students as co-authors in knowledge building by intentionally designed a lesson trajectory that helps students organize learning goals and integrate prior knowledge, practices, and explore uncertainties
Raising				
(Beghetto, 2020; Chen et al., 2019; Jordan, 2015; McDaniel et al., 2003)	This was not observed	Teacher problematized a phenomena only in the beginning of a topic to elicit interest and foster engagement with the topic (surface level / shallow problematization) ; teacher did not provide opportunity to dig into it for further exploration	Teacher intentionally problematized a phenomenon and provided time and opportunity for exploration of the same or continued topic ; Raised related uncertainty after an instance of reduction - purpose is to practice higher level thinking and problem-solving skills	Teacher intentionally problematized content to extend the phenomenon in a new way, direction, or application to practice higher level thinking and problem-solving skills/practices
Maintaining				
(Babrow et al., 1998; Chen et al., 2019; Jordan, 2015; Michaels & O'Connor, 2015)	This was not observed	Teacher invited students to ask new questions but did not allow space/time to develop the ideas or critique other arguments	Teacher compared conflicting ideas either from literature or student ideas without additional time to develop new arguments	Teacher challenged students to clarify and critique arguments/claims made and strategically compared conflicting claims to stimulate alternative ideas; rephrased questions to facilitate students' exploration of ideas
Reducing				
(Babrow & Matthias, 2009; Brashers, 2001; Jordan, 2015)	This was not observed	Teacher gave answers promptly at the first sign of struggle - does not give details of why/how	Teacher asked students to discuss questions or uncertainties in groups and/or provided an answer key or resources if they got stuck. If the teacher immediately provides an answer, they explain the concept or reasoning. Rephrasing a question or prompt in order to get to the correct answer	Teacher scaffolds the information to support students to seek information needed, guides students to correct answers without telling them, uses familiar phenomena-based evidence to explain target concepts
Postponing				
(Anderson, 2003; Brashers, 2001; Jordan, 2015)	This was not observed	Teacher does not answer student questions or uncertainties/walks away from students or groups that are verbally not understanding the content	Teacher asks students to hold onto their predictions, questions or uncertainties but does not re-address them later	Teacher re-addresses students prior uncertainties and questions that were initiated throughout the class

First Cohort Teacher Before Summer PD

- Teachers demonstrated a positive but limited awareness of students' uncertainty as a pedagogical resource.
- Teachers perceived uncertainty as a way to induce curiosity and persist through struggle.
- Teachers quickly reduced uncertainty, providing few opportunities for productive struggle during lesson enactment.
- Uncertainty reduction strategies resulted in fractured uncertainty navigation pathways in teacher constructed storylines.