

Exam Implementation of Scientific Epistemic Practices Curricula Through an Adaptive Expertise Lens: A Case Study

Zhitong Yang, University of Pennsylvania, zhitong@upenn.edu
Susan A. Yoon, University of Pennsylvania, yoonsa@upenn.edu
Clark A. Chinn, Rutgers University, clark.chinn@gse.rutgers.edu
Amanda Cottone, University of Pennsylvania, amandaco@sas.upenn.edu
Thomas Richman, University of Pennsylvania, trichman@upenn.edu
Noora Noushad, University of Pennsylvania, noora@gse.upenn.edu
Huma Hussain-Abidi, Rutgers University, hh429@scarletmail.rutgers.edu
Kyle Hunkar, Rutgers University, supposedly.kyle@gmail.com

Abstract: Scholars have suggested that one way to promote informed decision making about pressing socioscientific issues is to incorporate epistemic practices in science curricula. However, a key factor in teaching with such curricula is whether and how teachers can adapt instruction from their routine teaching approaches. Through an adaptive expertise lens, in this study, we examine how two teachers, teaching with agent-based computational complex systems models, varied in their implementations of epistemic practices and how consequently students' performance on epistemic practices was impacted. Through qualitative analyses of two teachers' implementation recordings, this study examines teachers' adaptive expertise in curricular implementations that aim at promoting student epistemic practices and provides examples of high and low levels of adaptive expertise that result in distinct student classroom experiences. This study carries implications for future teacher professional development geared towards improving students' epistemic practices.

Introduction

With the widespread misinformation on crucial socioscientific matters, such as vaccine safety and climate change, there is an urgent call to assist the general public in assessing scientific assertions (Herman et al., 2022; Osborne & Pimentel, 2022). Osborne and Pimentel (2022) pointed out that essential knowledge of science education, the method by which the scientific community produces reliable knowledge, is omitted from current educational settings, and stressed that the omission fails future citizens. They advocated that a goal of science education should be to enable students to become competent outsiders, capable of interacting with science and making scientific decisions in their lives. One way to address this challenge is to design curricula that involve students in exploring how to use reliable scientific practices when engaging with scientific topics in the public sphere (Chinn et al., 2023). Specifically, curricular designs should enable students to interact with scientific phenomena and build knowledge of scientific practices.

Through an NSF-funded project, we developed high school biology curricula with agent-based computer models of complex systems and emphasis on promoting student epistemic practices (Yoon et al., 2023). In the 2021-2022 school year, after a 10-day summer workshop, eight high school teachers implemented these curricula, and resulted in varied student classroom experiences. For some teachers, we observed a significant improvement from their students in using modeling practices to conduct scientific studies, examining criteria for good models, engaging in problem-solving and communicating with others, and connecting scientific reasoning to everyday life. However, for some other teachers, their students showed no improvement in these epistemic practices.

Past research has shown that successful implementation of new science curricula depends on whether and how teachers demonstrate adaptive expertise (Yoon et al. 2015; Yoon et al. 2019). Teaching curricula focused on promoting epistemic practices requires teachers to understand the goal of epistemic practices and adapt the curricula to their local educational settings, which necessitates a shift from teachers' routine expertise to adaptive expertise. In this study, we use the lens of adaptive expertise to examine how two teachers were able to adapt two of the curricular units in their class settings to promote epistemic practices. Through qualitatively analyzing two teachers' recordings of their classroom implementation, we sought to answer two research questions: (1) to what extent do teachers demonstrate adaptive expertise when implementing curriculum intended to promote students' epistemic practices, and (2) what do different levels of teachers' adaptive expertise look like? In the next section, we briefly review literature on epistemic practices and teacher adaptive expertise and outline the conceptual framework used to assess adaptive expertise.

Teaching epistemic practices

The shift in science education towards emphasizing scientific practices has become a recognized and established standard in science education (Duschl, 2008; NGSS, 2013). For example, in science classrooms, instructional methods should be geared towards nurturing students' epistemic practices, such as gathering and interpreting data to support claims with evidence, critically evaluating differing viewpoints, arriving at consensus, and adjusting beliefs based on new information. Epistemic practices are anchored in the notion of epistemic cognition which encompasses the beliefs and practices necessary for discovering, evaluating, and utilizing knowledge across different fields (Greene et al., 2016). Epistemic cognition pertains to an individual's thoughts and ideas about how knowledge is generated (Chinn & Rinehart, 2016; Greene et al., 2016). In the learning sciences, there has been a longstanding advocacy for science education to prioritize the actual methods and reasoning strategies employed by scientists. Duschl (2008) synthesized previous research and pointed out that science education should revolve around the epistemic frameworks used in developing and evaluating scientific knowledge and advocated for designing learning environments to promote epistemic practices. To establish clear goals for implementing epistemic practices, Barzilai and Chinn (2018) proposed the *apt-AIR* framework. They argued that epistemic practices comprise three key components of epistemic cognition. *Epistemic Aims and value* encompass the objectives and significance that people place on these aims, which may involve discovering information, developing explanations, or constructing persuasive arguments. *Epistemic Ideals* serve as the criteria used to evaluate the attainment of epistemic aims, such as the fitting of evidence into an argument. *Reliable epistemic processes* are the procedures, strategies, and methods with a higher likelihood of achieving epistemic aims, like selecting representative and sufficient samples in a study. The ultimate goal of teaching epistemic practices is to enhance students' competence in scientific practices, enabling them to succeed in interacting with socioscientific issues and decision-making.

Teachers' adaptive expertise

Teaching is a multifaceted endeavor characterized by its complexity, demanding that teachers tailor curricula and instructions to their unique, situated contexts (Anthony et al., 2015; Bowers et al., 2020). This involves handling non-routine events, identifying challenges and opportunities in both existing and unforeseen situations, and recognizing moments for effective instruction. Researchers have considered adaptive expertise as "applied creative thinking" (Gube & Lajoie, 2020) and examined the construct from different perspectives. For example, Mannikko and Husu (2019) found that teachers' ability to adapt was related to their use of two teaching orientations. A fixed orientation consists of a set of structured and preexisting knowledge, however, an open orientation to teaching is processed through situational cues by combining pre-existing knowledge with interactive observations, which are key factors for predicting adaptive expertise. Munson, Baldinger, and Larison (2021) proposed that thought experiments, in which teachers recontextualize and complicate practices, challenge simplification and raise questions from their own contexts, are associated with teacher adaptive expertise. Building on previous research, Yoon and colleagues (Yoon et al., 2015) identified three essential categories of adaptive expertise in teaching complex systems and subsequently validated the model (Yoon et al., 2019). These studies demonstrated that there is considerable variability in teachers' adaptive expertise and highlighted a connection between teachers' adaptive expertise and student learning outcomes. Within their model, *deeper level of understanding* refers to a teacher's proficiency in implementing extensions or making connections that facilitate a more profound level of knowledge construction. *Flexibility* in teaching is characterized by a teacher's keen awareness of their students' diverse needs, the ability to respond effectively to unexpected challenges, and the capacity to integrate new curricular activities within the specific context of their schools. *Deliberate practice* is manifested in a teacher's motivation, focused dedication, repeated efforts to monitor their practices, and the continuous development and testing of new approaches to enhance their teaching. Among the three categories of adaptive expertise, *deeper level of understanding* appears to be pivotal in deciding how *flexible* a teacher is able to be with customizing instruction and exercising *deliberate practice*. These studies demonstrated that analyzing science teaching through the lens of adaptive expertise can provide valuable insights into how teachers navigate contextual factors and offer a framework to assess the quality of curricular implementation. In this study, we use the adaptive expertise lens to examine how teachers adapted their instructions toward implementation of epistemic practices.

Conceptual framework

To foster epistemic practices among both teachers and students, it is essential to develop curricula that offer opportunities for engagement in scientific practices. These curricula should provide a platform for teachers and students to actively participate in the scientific processes used by scientists to advance their understanding of the

world. Building on these understandings, we developed science curricula to immerse high school students in the processes of data collection and analysis by employing complex systems modeling on an agent-based modeling platform that combines graphical blocks-based programming with a 3-D game-like interface (Yoon et al., 2023). These curricula encompass five self-contained units that explore a wide range of topics, from protein synthesis to ecology and evolution. In 2021, we further refined these units to place greater emphasis on components aimed at fostering epistemic practices. In our design of the curricula, both content and classroom activities are structured to specifically promote six key epistemic practices of the *apt-AIR* framework: (1) Develop arguments with evidence-based reasons, (2) consider and investigate multiple perspectives/hypotheses, (3) seek and use ample evidence, (4) seek and use conclusive, systematic evidence, (5) evaluate and interpret evidence consistently, and (6) align beliefs with evidence or modify beliefs to fit discrepant evidence.

However, the value of a teacher's knowledge is dependent on the specific educational context and is highly topic, person, and situation specific (Van Driel & Berry, 2012). Considering the intricacies of science education, the degree to which teachers can adapt curricula to their specific educational contexts is likely to significantly impact the successful implementation (Reiser, 2013; Wilson, 2013). In this study, using Yoon and colleagues' adaptive expertise framework (Yoon et al., 2015; Yoon et al., 2019), we analyzed classroom recordings of two teachers and illustrated how adaptive expertise is manifested in curricular implementation that aimed at promoting students' epistemic practices.

Methods

Context and participants

This study is part of a larger project aimed at enhancing teachers' understanding of epistemic practices and instructional practices through exploring computational models of complex systems. We engaged both content experts and high school teachers in a collaborative process of co-designing and refining the curricula to better facilitate epistemic practices. Then, in a 10-day summer workshop for teacher professional development, held in August 2021, the research team introduced participating teachers to epistemic practices and the *apt-AIR* model (Barzilai & Chinn, 2018). During the workshop, participants also discussed instructional strategies for promoting epistemic practices and how to extend their application to socioscientific issues. The primary objective of the workshop was to incorporate *apt-AIR* epistemic practices into science instruction and enhance teachers' comprehension and skills in supporting students' development of epistemic practices.

Throughout the 2021-2022 school year, we closely followed eight teachers in their classroom implementations to assess potential adjustments in their teaching practices and the resulting impact on their students. Half of the teachers taught at private, college preparatory schools and the other half taught at large suburban public schools in the north or southeastern U.S. On average, these teachers had ten years of teaching experience, with individual experience ranging from 5 to 18 years.

In addition to classroom observations, we employed a 50-item questionnaire and surveyed all students of the eight teachers to assess their classroom experiences before and after their curricular implementations. An exploratory factor analysis of the 50 items revealed six latent factors: connecting scientific reasoning in class to everyday life (F1), using modeling and modeling practices to learn about and do science (F2), attitudes towards learning science (F3), examining criteria for good models (F4), engage in problem-solving and communicating using multiple sources with others (F5), and opportunities for engaging in empirical investigations in the science classroom (F6). We calculated students' factor scores for both pre-survey and post-survey data and conducted a Repeated Measures Analysis of Variance to evaluate how student experiences changed from the pre-survey to the post-survey. The results indicated that improvements in student classroom experiences were not uniform, with some teachers' students showing significant increases in some or all factors, while other teachers' students showing no significant improvement.

Among the eight teachers studied, we found striking divergent classroom experiences from students taught by two specific teachers, Angela and Emily. Angela's students experienced a substantial decline in factor 1, which pertains to connecting scientific reasoning in the classroom to everyday life. Furthermore, they did not show any improvement in the other five factors. In contrast, students in Emily's class demonstrated significant improvements across all factors, except for factor 3, where there was a marginal *p*-value indicating some improvement. This pronounced contrast in student experience outcomes prompted the need for a closer look into the underlying reasons. Thus, in this study, we examined each of the two teachers' implementations of two curricular units on the topics of Enzymes and Sugar Transport. Both teachers had roughly the same number of years of experience (6 years and 8 years) and taught biology in roughly equivalent schools in Northeast USA in terms of social economic status levels.

Data sources

We analyzed complete classroom recordings of both teachers on implementing the two units (about 4 hours for each of the two teachers and about 2 hours for each of the two units). The classroom recordings enabled us to investigate the teachers' adaptive expertise across two different units and two different classes, and interpretations of teachers' adaptive expertise can be made in naturalistic settings. The debriefing session after the implementation of each of the two units were also recorded and used in this study. In debriefs, the course facilitator from the research team interviewed the two teachers with questions further probing teachers' knowledge and beliefs about the project, their contribution, and perspectives on success of the implementations.

Analysis

Classroom recordings and transcripts were analyzed qualitatively for instances that demonstrated adaptive expertise in the three categories. The definitions of the categories were derived from our previous studies (Yoon et al., 2015; Yoon et al., 2019) and were revised to fit the context of implementing curricula of epistemic practices. Levels of expertise were identified through an iterative mining of the classroom recordings. Examples that appeared to be high and low anchors of each category were discussed and agreed upon by the authors and used to construct the coding manual (see Table 1 below).

Table 1

Categorization Manual of Teachers' Understanding, and Implementation of Epistemic Practices as Demonstrated through Adaptive Expertise

Category and Definition	Examples
Deeper level of understanding A teacher understands the goal of the curricular units and is able to engage students in epistemic practices through content-related activities and dialogues. Low: there is no exhibition of understanding of the six epistemic practices, and classroom activities are not focused on exercising the practices. High: demonstrates deep understanding of the six epistemic practices and uses activities or dialogues to engage students in epistemic practices.	Low: In a group discussion designed to promote students to consider and investigate multiple perspectives or hypotheses, and through discussion, students would modify and align their beliefs with evidence, the teacher asked students for an answer to question 1. Once getting an answer from a student, the teacher said "alright," and then immediately moved to asking an answer for question 2. The teacher continued this process to the last question without probing questions to different answers or asking students to present their evidence and reasoning to back up their answers. <i>(The inference here is that the teacher does not possess a deeper level of understanding that the group discussion session is built for students to consider and investigate multiple perspectives or hypotheses and align their beliefs with evidence. Without all students sharing their perspectives, the discussion would not achieve the goal of the designed activity.)</i> High: After a student said that one data point is not correct, the teacher immediately probed the student with questions such as "how do you know it is not correct" until the student understood multiple trials are needed to obtain reliable data. <i>(Here the inference is that the teacher possesses a deeper level of understanding that the goal of the activity is to promote students to use ample, systematic evidence. So, the teacher guides the students with probing questions until the student understands ample and systematic evidence is the requirement of reliable process.)</i>
Flexibility A teacher is able to incorporate project expectations in a situated context, including changing content that reflects an awareness of student population, needs, and school context; pivoting instruction based on fluctuating student interests and/or other issues. Low: no adaptation is made facing diverse and unique needs from the student population or school/class context.	Low: The teacher knew that within the class time, it is impossible to cover multiple student group discussions. In this case, the teacher should revise the curriculum to focus on one or two group discussions in which the six epistemic practices could be exercised at a deep level. However, the teacher rushed her students through multiple group discussions without allocating sufficient time for her students to share their perspectives or present evidence of their conclusions. <i>(The inference here is that the teacher does not possess flexibility. Rushing through all group discussions without allocating sufficient time to any one of them will not enable students to exercise the epistemic practices at a deep level.)</i> High: The teacher provided light topics at the beginning of an implementation and asked students to debate between true and false statements. <i>(Here the inference is that the teacher was aware of her students' reluctance to share opinions and engage in debates with</i>

High: adds/revises the curriculum and instruction to fit in the needs of students.	<i>classmates. The teacher intended to use this activity to create a welcoming atmosphere and encourage evidence-based debate as a warm-up for the students.</i>
Deliberate practice A teacher demonstrates motivation, focus, and repeated effort to monitor practice, and reflects on a problem and devises new approaches to improve implementation. Low: A teacher thinks the class went well without reflecting or identifying issues with the implementations. High: A teacher exhibits deep reflection and design steps to improve in next rounds of implementation with enthusiasm.	Low: In an implementation, the teacher read the correct answers to all students, and then students copied the correct answers to their worksheets. In the debrief at the end of the class, the teacher said, “I think they answered questions really well in the packet when talking about why we have a class average versus just looking at our data.” (<i>Here the inference is that the teacher didn’t reflect on whether students had grasped the epistemic practice of using ample evidence. Students should understand why ample evidence is needed in reliable process by comparing their data to the class average, rather than merely recording the average.</i>) High: In debrief, the teacher reflected on different patterns between small group discussion and whole class discussion; reflected on different paces of different groups of students in completing assigned tasks; planned next rounds of implementations with enthusiasm. (<i>Here the inference is that the teacher metacognitively monitors how her students exercise the epistemic practices through group discussions and makes an effort to improve later implementations.</i>)

Findings

In this section, we present instances that emerged from the data sources that illustrate teacher’s levels of adaptive expertise in each of the three categories. The cases are presented in an order of low to high adaptive expertise. For context, descriptions of the situation or explanations of the curriculum are provided in square brackets wherever they are needed.

Angela

Overall, Angela exhibited challenges in navigating the curricula and engaging students in epistemic practices. This was manifested in a few ways. First, she exhibited a low level of *deeper level of understanding* of the project’s goal. Angela read the curriculum guide with little deeper level of interpretation of the tasks. Instead of using the epistemic callouts embedded in the curricula to engage students in the six epistemic practices, she often confirmed students’ answers without probing deeply into students’ conclusions. Below is an example.

So, for this discussion and the groups want to tell us what claims A, B or C. [after a student provided an option B] Okay, alright, so we've got a claim B. Anybody got a different claim than what is just said. [after another student provided an option C] Ok, you said C. All right, anybody got anything else... any other group choose B? and any other group choose C? [after seeing most students raised hands for option C] All right, I've seen a consensus of a choice C, and that [read the claim C] Enzymes find substrates like a traveler without a map...

The discussion activities in the curriculum are designed to provide students with opportunities to consider multiple perspectives or hypotheses. In addition, in the curriculum, an epistemic callout is embedded to remind instructors that this is a good opportunity to connect to the fact that real-world scientists are not just trying to collect evidence to prove their hypotheses, but rather they understand multiple hypotheses are all possible. Therefore, a consensus should be reached through sharing data and evidence-based reasoning. Angela in this case could have encouraged students to take into account the possibility of different hypotheses of phenomena. In doing so, she could have given students an opportunity to elaborate on their perspectives or foster relevant discussions centered on examining multiple hypotheses and modify their beliefs to fit with evidence.

In terms of *flexibility*, she had some challenges in adapting the curricula to fit in the available class time while engaging students in the six epistemic practices. For example, in her debrief, she acknowledged that she had anticipated that there could be too many activities to cover within the limited time, however, she didn’t make necessary modifications to the Enzymes unit so that it was manageable for her students. She said,

I really wanted them to build their evidence skills and reasoning skills. And I think there were two CERs in the previous version, and this one has three CERs incorporated with it. Because of the activity that I did last week, I tried to incorporate CERs within it, but I think that it was too much of a jump for them, it was a little bit more of a challenging ...

Here, CER stands for Claim-Evidence-Reasons. Angela used the term to refer to student discussion activities in which the six epistemic practices are to be exercised. This excerpt implied that before the implementation, Angela was aware that covering three group discussions within the class time would be challenging. Had she understood that the goal of the discussions was to promote the epistemic practices of considering multiple perspectives and seeking and using ample evidence, she would have chosen to focus on one or two CERs to allow students time to delve deeply into the practices, and share their perspectives, evidence, and reasoning.

Angela needed to be more critical and creative in her *deliberate practice*. She often assumed that all her implementations went well without reflecting on issues or identifying areas to improve. In her post-implementation debrief session, reflecting on how everything went in the Enzymes unit, she said,

It's kind of funny the big difference between my A class and my B class. My A class definitely took a little bit longer to get into it and actually focus on doing the lab... I listened to a podcast that was on New York Times, one of the teachers on this podcast had mentioned just the social emotional learning of our students and where they're at right now, and I think that is what is the biggest challenge. I think that's one of the reasons why I think that some of my students would struggle.

Here, she attributed the lack of success to her students' perceived inability to sustain attention in the classroom. Instead of considering how to adapt the unit to engage these students in exercising the six epistemic practices, she predominantly focused on the students' perceived limitations. Although she reflected on a possible cause of the issue, she didn't appear motivated to explore new approaches, such as dividing students into groups to debate different opinions so that the six epistemic practices could be exercised. Her perception seemed to assume there was no viable way to enhance the instructional process given the students' perceived limitations.

Emily

In contrast to Angela, Emily demonstrated a *deeper level of understanding* of the six epistemic practices. Throughout the implementations, she frequently and purposefully used activities designed in the curricula to engage students in epistemic practices. For example, in the student guide, there is a group discussion in which students are asked to choose among three claims, and then run simulations and provide evidence to support the claim that they have chosen. The design of the discussion is to provide students with an opportunity to consider and investigate multiple perspectives or hypotheses, both correct or incorrect, and align their beliefs to fit evidence. After allowing students a while to follow the student guide and conduct simulations, Emily paused the activity and purposefully assigned certain student groups to support certain claims. Below is the excerpt.

Alright. We will do a little differently this time... There's three claims and it says one responsible for So, I'm feeling that by just asking you guys what's right. You're gonna all say similar things, but I want to explore this a little bit so I'm gonna assign these two groups to claim A... and I want you to tell me if claim A is correct... The two groups in the lab tables, I'm gonna assign you claim B... [then assigned other students to claim C] What specific evidence would you see in the simulation if C was correct?

In the debrief, Emily explained why she assigned students to support a specific claim rather than allowing students to choose a claim to support. She aimed to encourage her students to consider alternative hypotheses rather than simply selecting the most plausible option without assessing the validity of the others. She intentionally asked some students to prove inaccurate claims to create some tension by which to lead some engaging discussions. The video recording confirmed that her approach successfully engaged students in vibrant discussions, and a few students continued that discussion even after the whole-class discussion. Without this deeper level of understanding, the activity might not sufficiently prompt students to consider and investigate multiple perspectives or hypotheses and adjust their beliefs to discrepant evidence.

Emily also demonstrated a high level of *flexibility*. Facing limited class time, she purposefully reduced the number of student group discussions and revised the student handout. During the debrief, she explained,

Over the weekend when I was planning for this, I really felt like I was guilty especially with the big packet, just being like, ok, we need to get to the right answer. And once we are there, we need to immediately pick that up or we are not going to finish... So that was like me trying to kind of, let's actually take some time on this group discussion and I modified the student handout so it only had this one group discussion so we could take the time.

The reflection demonstrated Emily's adaptive expertise of *flexibility*. With a deeper level of understanding of the goal of student discussion, she incorporated the project expectation in one student group discussion so that her students would be able to take time to practice the six epistemic practices. Furthermore, realizing that her students, especially those anxious ones, might be frantic to finish the big worksheet, Emily broke it into three sections so that students would not feel that they have so much left to go. The revised student handouts enabled students, especially those who worked slower but at the deepest level, to engage deeply with the six epistemic practices. Emily's ability to adapt and refine student materials highlighted her *flexibility* in adapting the unit to the constraints of limited class time and students' needs.

Finally, Emily showed a high level of *deliberate practice*. She thoroughly reviewed the curriculum before implementing each unit, and constantly reflected on issues and thought about new approaches to improve instructions. For example, in her debrief of the Sugar Transport unit, she shared valuable insights gained from running the simulation herself. She acknowledged that, prior to running the simulation, she had taken certain concepts for granted. However, the experience of running the simulation really made her understand how random moves resulted in diffusion. The thorough preparation enabled her to precisely guide one student group in seeking and using ample evidence when observing the patterns of molecular motion. In addition, reflecting on student group discussions, Emily noticed that the whole-class discussion had been a challenging task for her students. She didn't have a solution at the time; however, she continued planning the next implementation with enthusiasm. She said, "I think I'm gonna keep trying it. It's just hard... I think I will keep going and see how it goes on Thursday with the different class with the different vibe." Here, facing challenges, Emily was still motivated to monitor her classroom activities and search for solutions to improve implementations.

Discussion

We were interested in whether and how teachers implement curricula anchored in epistemic practices through an adaptive expertise lens. The findings suggest that attending to teachers' adaptive expertise can help us understand how teachers implement these curricula. In our analysis, *deeper level of understanding* emerged as pivotal and significantly impacted these teachers' *flexibility* in customizing the curricula and *deliberate practices* in reflecting on their implementations and planning for future implementations. Teachers' levels of understanding of the goal of epistemic practices led to different patterns of enactments of the curricula. Emily's grasp of *deeper level of understanding* led her to teach the units in a way in which she effectively utilized activities designed in the curricula to promote epistemic practices among students. In contrast, without this deep understanding, Angela was challenged to use the designed activities to promote epistemic practices, such as multiple hypothesis testing (Chinn et al., 2023). In addition, the different levels of adaptive expertise could explain the different classroom experiences between the students of the two teachers. For example, the decline in Angela's students with connecting scientific reasoning in class to everyday life (F1) can be explained by the fact that she didn't allocate sufficient time for her students to exercise the six epistemic practices through discussions. Designing curricula is necessary for promoting epistemic practices in science education (Chinn et al. 2023; Osborne & Pimentel, 2022). Following this line of research, we found that the lens of adaptive expertise enables us to understand how teachers adapt such curricula and what support they may need. We acknowledge the limitations of our case study, which is based on only two self-selected teachers. Thus, we cannot draw broad generalizations. However, the case study showed that to successfully implement epistemic practices (i.e., the *apt-AIR* framework), teachers' adaptive expertise needs to be examined and supported.

References

- Anthony, G., Huner, J., & Hunter, R. (2015). Prospective teachers development of adaptive expertise. *Teaching and Teacher Education*, 49, 108–117.
- Barnett, S. M. & Koslowski, B. (2002). Adaptive expertise: effects of type of experience and the level of theoretical understanding it generates. *Thinking & Reasoning*, 8(4), 237–267.
- Barzilai, S., & Chinn, C. A. (2018). On the Goals of Epistemic Education: Promoting Apt Epistemic Performance, *Journal of the Learning Sciences*, 27(3), 353–389.
- Bowers, A., Merritt, E., & Rimm-Kaufman, S. (2020). Exploring teacher adaptive expertise in the context of elementary school science reforms. *Journal of Science Teacher Education*, 31(1), 34–55.
- Chinn, C. A., & Rinehart, R. W. (2016). Epistemic cognition and philosophy: Developing a new framework for epistemic cognition. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.). *Handbook of epistemic cognition* (pp. 460–478). New York, NY: Routledge.

- Chinn, C. A., Yoon, S. A., Hussain-Abidi, H., Hunkar, K., Noushad, N. F., Cottone, A. M., & Richman, T. (2023). Designing learning environments to promote competent lay engagement with science. *European Journal of Education*, 00, 1–15. <https://doi.org/10.1111/ejed.12573>
- Duschl, R. A. (2008). Science education in 3-part harmony: Balancing conceptual, epistemic and social goals. *Review of Research in Education*, 32, 268–291.
- Gube, M., & Lajoie, S. (2020). Adaptive expertise and creative thinking: A synthetic review and implications for practice. *Thinking Skills and Creativity*, 35, Article 100630.
- Greene, J. A., Sandoval, W. A., & Bråten, I. (Eds.). (2016). *Handbook of epistemic cognition*. New York, NY: Routledge.
- Hand, B., Cavagnetto, A., Chen, Y. C., & Park, S. (2016). Moving past curricula and strategies: Language and the development of adaptive pedagogy for immersive learning environments. *Research in Science Education*, 46(2), 223–241.
- Herman, B. C., Clough, M. P., & Rao, A. (2022). Socioscientific issues thinking and action in the midst of science-in-the-making. *Science & Education*, 31, 1105–1139.
- Leu, D. J., Kinzer, C. K., Coiro, J., Castek, J., & Henry, L. A. (2013). New literacies: A dual-level theory of the changing nature of literacy, instruction, and assessment. In R.B. Ruddell & D. Alvermann (Eds.). *Theoretical Models and Processes of Reading*, Sixth Edition, Newark, DE: IRA
- Mannikko, I., & Husu, J. (2019). Examining teachers' adaptive expertise through personal practical theories. *Teaching and Teacher Education*, 77, 126–137.
- Muis, K. R., Trevors, G., & Chevrier, M. (2016). Epistemic climate for epistemic change. In J. A. Greene, W. A. Sandoval, and I. Bråten (Eds.), *Handbook of epistemic cognition* (pp. 331–359). Routledge.
- Munson, J., Baldinger, E. E., & Larison, S. (2021). What if...? Exploring thought experiments and non-rehearsing teachers' development of adaptive expertise in rehearsal debriefs. *Teaching and Teacher Education*, 97, Article 103222.
- National Research Council. (NRC, 2014). *STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research* (Committee on Integrated STEM Education; National Academy of Engineering. Margaret Honey, Greg Pearson, and Heidi Schweingruber, Eds.). Washington, DC: National Academies Press.
- Osborne, J., & Pimentel, D. (2022). Science, misinformation, and the role of education. *Science*, 378(6617), 246–248.
- NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States*. Washington, DC: The National Academies Press.
- Osborne, J., & Pimentel, D. (2023). Science education in an age of misinformation. *Science Education*, 1–19.
- Reiser, B., J. (2013). What professional development strategies are needed for successful implementation of the next generation science standards? *Invitational Research Symposium on Science Assessment*.
- Van Driel, J. H., & Berry, A. (2012). Teacher professional development focusing on pedagogical content knowledge. *Educational Researcher*, 41(1), 26–28.
- Wilson, S. M. (2013). Professional development for science teachers. *Science*, 340, 310–313.
- Yoon, S. A., Evans, C., Miller, K., Anderson, E., & Koehler, J. (2019). Validating a model for assessing science teacher's adaptive expertise with computer-supported complex systems curricula and its relationship to student learning outcomes. *Journal of Science Teacher Education*, 30(8), 890–905.
- Yoon, S. A., Koehler-Yom, J., Anderson, E., Lin, J., & Klopfer, E. (2015). Using an adaptive expertise lens to understand the quality of teachers' classroom implementation of computer-supported complex systems curricula in high school science. *Research in Science and Technology Education*, 33(2), 237–251.
- Yoon, S., Shim, J., Miller, K., Cottone, A. M., Noushad, N. F., Yoo, J-U., Gonzalez, M. V., Urbanowicz, R., & Himes, B. E. (2023). Professional development for STEM Integration. Analyzing Bioinformatics teaching by examining teachers' qualities of adaptive expertise. In A.C. Superfine, S.R. Goldman, & M-L. M Ko (Eds.). *Teacher Learning in Changing Context, Perspectives from the Learning Sciences*, First Edition, New York: Routledge.

Acknowledgments

This material is based upon work supported by the National Science Foundation under Grant No. 579971. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.