Chapter 6
Scientific Argumentation as an Epistemic Practice: Secondary Students' Critique of Science Research Posters

Yann Shiou Ong, Richard A. Duschl, and Julia D. Plummer

Abstract Scientific argumentation has been an actively researched topic for almost 30 years. Predominant school science argumentation interventions focus on students constructing arguments using a component's template to produce good scientific arguments. In recent years, researchers have called for a shift toward interpreting argumentation as an epistemic practice comprising critique in addition to the construction of scientific claims. This chapter presents a study that looked at argumentation through a different lens—the epistemic practice approach to argumentation—that emphasizes students' critique of others' epistemic products (e.g., a science poster) as the trajectory for developing students' critical stance in argumentation. The study took place in a Singapore secondary school's inquiry course. Student-teacher discourse during a science research poster critique activity is examined between groups in two learning environments: student-centered critique (Class A) versus teacher-centered critique (Class B). Prior to the poster critique activity, Class A students experienced student-centered critique instruction and practiced critiquing literature using scientific soundness criteria (SSC). Class B students experienced teacher-centered critique instruction whereby the teacher proposed ideas for students' inquiry project, students reviewed literature by summarizing, and the teacher critiqued students' review. Findings on groups' productive disciplinary engagement in critique and construction (PDE-CC) practices and incorporation of PDE-CC guiding principles—problematizing, resources, disciplinary accountability, and epistemic authority—suggest the alternative approach of developing students' critical stance via engagement in critique practices using critique criteria is a promising approach to improve critique practices in the science classroom.

Y. S. Ong (✉)
National Institute of Education, Nanyang Technological University, Singapore, Singapore
e-mail: yannshiou.ong@nie.edu.sg

R. A. Duschl
Southern Methodist University, Texas, USA
e-mail: rduschl@smu.edu

J. D. Plummer
Pennsylvania State University, Pennsylvania, PA, USA
e-mail: jdp17@psu.edu

T. W. Teo et al. (eds.), *Science Education in the 21st Century*,
https://doi.org/10.1007/978-981-15-5155-0_6

Introduction

In the era of "fake news" and "alternative facts", it is pertinent for citizens to take an appropriately critical stance when making sense of claims and arguments that impact decisions ranging from personal to social, to national, and international levels. When presented with a claim, a person who takes a critical stance toward the claim would consider how and why it might not be credible or sound. Engaging students in scientific argumentation has been argued to support students' critical thinking by developing their reasoning and epistemic criteria for evaluating knowledge claims (Jiménez-Aleixandre & Erduran, 2007). While there is a general consensus among science educators that scientific argumentation is an essential part of science education, promoting a critical stance in science classrooms that value scientific argumentation remains a challenge (Henderson, McNeill, González-Howard, Close, & Evans, 2018).

A current issue with existing scientific argumentation research is the lack of framing scientific argumentation as an epistemic practice. Interventions typically provide students with tools for argument construction but pay little attention to the context which motivates the practice (Manz, 2015). Furthermore, although science education researchers acknowledge scientific argumentation comprising of both critique and construction practices, existing school science argumentation interventions overemphasize argument construction with insufficient attention on critique (Ford, 2008; Henderson, MacPherson, Osborne, & Wild, 2015). The study reported in this chapter addresses this gap by examining critique practices in a Singapore secondary school's inquiry course. Student–teacher discourse during a science research poster critique activity at the secondary two level is examined between groups in two learning environments: student-centered critique (intervention Class A) versus teacher-centered critique (comparison Class B). The study research questions (RQs) are: (RQ1) To what extents do groups demonstrate productive disciplinary engagement in critique and construction of claims? and (RQ2) To what extents are the guiding principles for fostering PDE-CC—*problematizing*, *resources*, *disciplinary accountability*, and *epistemic authority*—incorporated in the critique activity?

The chapter begins by reframing scientific argumentation through the lens of an epistemic practice. We introduce the productive disciplinary engagement in critique and construction of claims (PDE-CC) framework, based upon Engle and Conant's (2002) productive disciplinary engagement (PDE) framework. The PDE-CC formed the study's analytic framework and informed the intervention design in a larger research project (Ong, 2018) which the study draws upon. Next, we describe the study context and participants to situate our study, and outline the data analysis procedures. We then present our findings and discussions. The chapter concludes with implications from findings and suggestions for future research to drive the scientific argumentation research agenda forward.

Reframing Scientific Argumentation as an Epistemic Practice

A review of the classroom argumentation literature reveals researchers predominantly framed scientific argumentation as an epistemic tool use issue (Manz, 2015). Students learn to argue using scientific argument component scaffolds, such as the Toulmin Argument Pattern (TAP) (Osborne, Erduran, & Simon, 2004) or the Claims-Evidence-Reasoning (CER) framework (McNeill, Lizotte, Krajcik, & Marx, 2006). Studies evaluating students' argumentation skills based on the components in their arguments have identified students' inadequacies, such as their inability to select appropriate data as evidence (McNeill & Krajcik, 2007), lack of reasoning or considering scientific principles (McNeill et al., 2006), and inadequate rebuttals (Osborne et al., 2004). However, studies that attended to the social context of students' argumentation suggests students' arguments reflected what students considered as relevant components for the context rather than students' lack of argumentation skills (Berland & Hammer, 2012; Kelly et al., 1998). Thus, the research literature suggests a need to reframe scientific argumentation as an epistemic practice which involves epistemic tool use adapted to relevant contexts (Manz, 2015). Considering scientists' epistemic practices, scientific communities' main goal is to build sound scientific knowledge claims to explain natural phenomena (Driver, Asoko, Leach, Scott, & Mortimer, 1994). Science studies literature suggests this goal is achieved via epistemic practices of proposing, communicating, evaluating, and legitimizing knowledge claims (Kelly, 2016). Constructing claims (i.e., proposing and communicating claims) and critiquing or evaluating claims are both essential epistemic practices for knowledge building. Yet, critique is undervalued and rarely present in science classroom discourse (Henderson et al., 2015).

Productive Disciplinary Engagement in Critique and Construction

Findings reported in this chapter came from a larger study (Ong, 2018) aimed at designing an intervention to foster critique and construction practices. To design the intervention and evaluate its effectiveness, Engle and Conant's (2002) productive disciplinary engagement (PDE) framework was interpreted in the context of critique and construction practices, giving rise to the productive disciplinary engagement in critique and construction of claims (PDE-CC) framework. The PDE-CC framework's three dimensions—*engagement*, *disciplinarity*, and *productivity*—articulate what taking a critical stance toward scientific arguments looks like in group discourse. The three dimensions are elaborated as follows: *Engagement* concerns how and to what extent participants interact with others' ideas when critiquing or constructing claims. Synthesizing Walton's (1998) argumentation dialog types and the Interactive, Constructive, Active, and Passive (ICAP) cognitive engagement modes framework

(Chi & Wylie, 2014), the PDE-CC framework distinguishes the following discursive engagement levels. The highest engagement level is critical stance discourse, demonstrated in "critical discussions" where presented challenges are discussed extensively. "Joint idea-building" discourse involves adding and supporting ideas where challenges may be present but not further discussed. "Information-seeking" discourse comprises a series of questions and responses around an idea. The lowest engagement level is "exposition" discourse where one or more ideas develop in parallel.

Taking a critical stance in a *disciplinary* way means participants' critique and construction of scientific arguments resembles how and what scientists critique and construct. Hence, discourse is disciplinary if the discussion topic involves critical epistemic decisions that impact inquiry outcomes (Grandy & Duschl, 2007) and utilizes epistemic criteria valued by scientists, i.e., scientific criteria to support or challenge scientific arguments. Four critical epistemic decisions (EDs) (Grandy & Duschl, 2007) are: (ED1) What data to collect and how to collect them?; (ED2) What data to select as evidence?; (ED3) How to represent and analyze selected data; what models, patterns, or conclusions can be generated?, and (ED4) What is the most scientifically sound explanation for the model/pattern? Scientific criteria include: "justification" (whether a claim is justified), "internal coherence" (i.e., causal mechanism in scientific explanation; coherence among evidence, explanation, research question, and overall argument), "process reliability and validity" (i.e., use of control of variables strategy; whether measurements are valid indicators of variables), and "external source" (referencing sources other than what one knows/thinks). Non-scientific criteria include: "practicality" (whether the idea is feasible or applicable in real life), "agreement with personal experience" (i.e., anecdotal evidence), "communication goodness" (clarity and understandability of argument; appropriate use of scientific representations, e.g., diagrams), and "others" (any other non-scientific criteria).

Since an epistemic goal of scientific communities is to iteratively build sound knowledge claims through peer critique (Longino, 2002), the *productivity* dimension concerns whether group critique/construction leads to improvement of scientific claims or ideas valued by a knowledge building community (Scardamalia & Bereiter, 2003). Group discourse is "highly productive" if it leads to an "improved decision" with stronger justifications using scientific criteria, or a decision that overcomes identified error or problem. Discourse is "moderately productive" if it leads to "identifying an error" or problem in the initial decision/critique, or if the group "addresses the critique" by rebutting challenges or defending the initial decision/critique with non-scientific criteria, so the initial decision/critique holds. Discourse is "minimally productive" if it only leads to "making a decision" or making a critique.

PDE-CC's four guiding principles—*problematizing*, *resources*, *epistemic authority*, and *disciplinary accountability*—functioned as intervention design principles to support students' PDE-CC, as well as analytical principles for explaining the extents to which the three PDE-CC dimensions were observed in students' discourse. *Problematizing* refers to the extent to which the activity or problem taken up by students is genuinely uncertain and meaningful. Intervention critique activities were designed to scaffold students' critique of epistemic products, including the science research poster critique activity reported in this chapter. Such critique activities form the contexts for scientists' important epistemic practice. *Resources* refer to physical, technological, or conceptual tools that support students' critique. In the intervention class, three scientific soundness criteria (SSCs) relevant to reliability and validity in scientific inquiry were co-developed with the students as an epistemic tool to guide critique. The SSCs are: (1) use of accurate and reproducible data to answer research question, (2) conclusion is based on good data interpretation and inference, and (3) consideration of scientific concepts and methods accepted and used by recognized experts. *Epistemic authority* refers to shared epistemic authority among students and teachers to challenge ideas, resolve problems, and make epistemic decisions. Intervention critique activities were designed for shared epistemic authority among students and teachers to critique students' epistemic products. Finally, *disciplinary accountability* refers to holding students' ideas accountable to scientific criteria, i.e., challenging students' ideas and critiques based on scientific criteria. The intervention utilizes SSCs as an epistemic tool for students and teachers to hold ideas accountable to scientific criteria. The intervention's approach of holding students' ideas accountable to the discipline from the start follows Forman and Ford's (2014) conjecture that critique practices first occur on the interpersonal plane then the intrapersonal plane. That is, students, learn to critique peers' arguments before becoming better at critiquing their own arguments.

Research Methods

Detailed description of the study context and illustration of the analyses are reported elsewhere (Ong, 2018; Ong, Duschl, & Plummer, 2018). In the interest of space, details of the study context and participants, as well as the data analysis, are described in this chapter to the extent necessary for interpreting the findings.

Study Context and Participants

The larger research study spanned three school semesters in a highly selective Singapore public school that admits top performers in the national examination conducted at the end of primary school education (i.e., end of sixth grade). Students enrolled in the school are typically high achievers in math and science. The school offers an inquiry course for all secondary two/three (eighth/ninth grade) students. Two science classes, the intervention (Class A) and a comparative class (Class B) participated in the research study. Class A comprises Mr. Gan and groups A1 and A2. Class B comprises Ms. Lee and groups B1 and B2. All names are pseudonyms. The first author acted as a co-teacher, moving between both classes to facilitate the lessons and group discussions when the teacher was absent or when students requested assistance. Both teacher participants are physics teachers with prior experiences mentoring middle and high school students in science research and conducting physics research as undergraduates. Mr. Gan had longer teaching experience (seven years) while Ms. Lee (three years' teaching experience) had more extensive research mentoring experience as she had also mentored undergraduate students.

Each class met once a week for 1.5 h over 34 weeks. In semester one, student groups conducted a literature review and planned investigations relevant to their selected scientific inquiry project. Groups carried out their inquiry over semesters two and three. The intervention took place from lessons five to ten in semester one. Prior to the poster critique activity (lessons five to seven), Class A students—together with the researcher and Mr. Gan—co-developed the three scientific soundness criteria (SSC) and practiced using the SSCs to critique scientific literature (e.g., journal articles). In Class B, Ms. Lee introduced a good model of scientific inquiry research (in the form of a high-quality, student-produced scientific research presentation) and suggested relevant scientific concepts and research ideas for groups' consideration. Class B students reviewed literature (e.g., journal articles related to their inquiry project) by summarizing. Overall, Class A instruction can be described as student-centered critique instruction while Class B instruction can be described as teacher-centered critique instruction.

The science research poster critique activity required groups to select and critique one science research poster using a review handout. The posters were produced by students in the previous inquiry course cohort. Students were encouraged to select a physics-related poster or one that is relevant to their own inquiry project. Class A's poster review handout instructed students to "[e]valuate the scientific soundness of the poster using the scientific soundness criteria. Include the critical questions you used and the corresponding responses from the poster/presenter to support your evaluation". Class B's handout instructed students to "[e]valuate the poster. Say what is good about the poster and the research reported, and what is not so good about it". Class B's instruction was worded to convey the idea of evaluating the reported research, not just the poster design. Class B's instructions thus matched Class A's instruction without using the term "scientific soundness", which was unfamiliar to Class B students.

Data Analysis

To answer the research questions, event maps (Kelly, Brown, & Crawford, 2000) were created from reviewing the video recordings during the scientific poster critique activity in both classes to provide an overview of main classroom activities within the lesson. An event map is a tool that demarcates phases comprising thematic activities of students and teachers. A phase unit comprises concerted and coordinated thematic talk and action among participants; that is, a common focus for a segment of group exchanges (Kelly et al., 2000). Examples of phase units during Class A's poster critique activity include: (1) teacher gives instructions for poster critique activity and provides electronic copies of scientific posters to groups, (2) groups look through

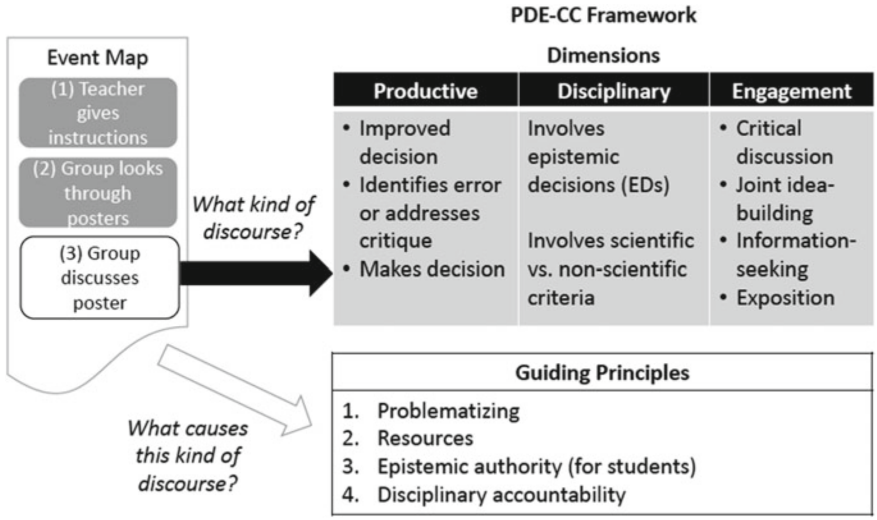

Fig. 6.1 PDE-CC as an analytic framework

posters, followed by (3) groups critique selected posters and fill in the electronic copy of a poster review handout. Phase units relevant to students' engagement in poster critique were identified and transcribed. Groups' poster review handouts were examined to clarify discussions.

To answer RQ1, each group's discourse transcript was analyzed for the levels of engagement patterns, disciplinarity extent, and productivity extent described in the PDE-CC framework section. To answer RQ2, evidence of incorporating each PDE-CC principle throughout the poster critique activity was sought: 1. *Problematizing*—Did students see poster as an epistemic product for critique and are the critiques meaningful? 2. *Resources*—What resources are provided to help students with critique? 3. Epistemic *authority*—Who challenges the initial critiques presented? and 4. *Disciplinary Accountability*—Are students' initial critiques held accountable to scientific criteria? Figure 6.1 provides an overview of using the PDE-CC framework, comprising three dimensions and four guiding principles, for analysis.

Findings and Discussion

For the purpose of this chapter, findings from A1 (comprising students Charles, Sue, and Xander) and B1 (comprising students Ariel, Norman, and Varun)'s poster critique activity are presented for PDE-CC comparison as both groups reviewed the same hovercraft poster. Both A1 and B1 demonstrated higher PDE-CC extents within their class. PDE-CC extents of the other two groups, A2 (students Jane, Kang, and Victoria) and B2 (students Audrey, Debbie, and Livie) are summarized. This is followed by a discussion on how PDE-CC guiding principles were incorporated during the critique activity, which could account for the different PDE-CC extents observed.

PDE-CC Extents Between Classes

In terms of *engagement*, groups A1 and B1 each demonstrated one instance of student-led "critical discussion" as their highest engagement level. A1's 'critical discussion' occurred as students disagreed over the problem with the poster. Sue opined the reported hovercraft inquiry "doesn't exactly answer the research question". Xander disagreed with Sue's characterization of the problem and instead framed it as a "reliability issue". Sue and Charles went on to persuade Xander the research question was not answered because the poster only reported the effect of a single position of the propellers on hovercraft speed. There was no comparison with other "examples", such as other positions or different numbers of fans (i.e., propellers). The propellers' position was not varied in the way experiments testing a variable ought to when investigating the variable's effect. A1's "critical discussion" occurred over 19 speaker turns. In comparison, B1's "critical discussion" occurred only over eight speaker turns. It started with B1 members trying to make sense of the hovercraft design, which led to Norman's critique: the poster did not explain how the hovercraft was created. Varun challenged Norman's critique, claiming the hovercraft was as described in the poster and did not require construction. Ariel pointed out the poster described cardboard with holes, implying cardboard with holes were not hovercrafts. Varun then corrected himself, stating nozzles were fitted in the cardboard to construct the hovercraft. Norman challenged the existence of nozzles. Varun and Ariel added details about the nozzles, which implies the poster did explain to some extent how the hovercraft was created, thus countering Norman's initial critique. The episode concluded with Norman stating, "the methodology could be clearer".

For *disciplinarity*, A1's main critiques focused on ED1: What data to collect and how to collect them. During their "critical discussion", A1 was concerned over the problem with the hovercraft poster's research design: whether it did not answer the research question or had a reliability issue. A1's other critiques involved the poster's lack of details around the data collection method, such as the poster did not specify the type of hovercraft used, precise propeller positions, and fan speed (a fan is used to move the hovercraft). A1's critiques utilized scientific criteria, including "justification" and "reliability and validity of processes". For B1, in addition to critique around ED1 exemplified in their "critical discussion" as described, discussions around other posters (while selecting one to review) focused on how well information was communicated and the appeal of the poster design. For instance, B1 students commented on whether a poster was "readable" with "no overly scientific words", whether pictures and diagrams were used and occupied an appropriate amount of space, and whether poster design was engaging. Overall, B1's critiques utilized a mix of scientific (referencing poster as "external source" of information to challenge Norman's claim during their "critical discussion") and non-scientific criteria ("communication goodness" and "others-aesthetics").

As for *productivity*, both groups' "critical discussion" were "moderately productive". A1's "critical discussion" led to addressing Xander's challenge to Sue's identification of the poster's research design problem. B1's "critical discussion" led to "identification of errors" in Norman's initial critique that the poster did not describe how the hovercraft was made. For the other two groups, A2 only engaged in "exposition" during their poster critique. Their critique involved their selected poster's lack of control of variables and was disciplinary as it focused on ED1 and involved the "reliability and validity of processes" scientific criterion. However, A2's discourse was "minimally productive" as it only led to the group making a critique. On the other hand, B2's highest engagement level was "information-seeking" over seven turns with their teacher. B2's discourse lacked disciplinarity as their critique focused on the poster's aesthetics and applicability of the research instead of focusing on the EDs. However, Livie did use the "internal consistency" scientific criterion to rebut Ms. Lee's critique by claiming the research design was still logical despite not reaching the intended application outcome (the brief rebuttal with no following discussion did not qualify as "critical discussion" engagement). Based on the student's rebuttal, B2's discourse was "moderately productive" as it led to the identification of an error in the initial critique. Overall, the main difference in PDE-CC between A1 and B1 and across classes lies in *disciplinarity*.

PDE-CC Guiding Principles Incorporation

Groups' PDE-CC demonstrated during the poster critique activity make sense in light of the extents to which PDE-CC guiding principles were incorporated. Evidence of incorporating all four PDE-CC guiding principles was found during A1's scientific poster critique activity. A1 students spontaneously looked for errors in their selected poster (*problematizing*). Sue cued the use of SSCs at the start of their critique activity (*resources*) by asking "what's the three criteria". Throughout the group discussion, Mr. Gan constantly held students' critiques accountable to the scientific criterion of "justification" (*disciplinary accountability*) and positioned students to *share epistemic authority* when critiquing ideas. Mr. Gan pressed Sue to justify her claim by providing specific examples and evidence, and directed students to engage in peer discussions instead of directing their response toward the teacher. Mr. Gan only modeled how to critique by providing his critique after students gave their initial critiques. Additionally, Mr. Gan supported Sue's points of view by evaluating them as "very, very important" and "very, very good points". Mr. Gan's support is important for achieving shared epistemic authority among students in view of previous lessons where Xander dominated critique within the group and among Class A students at times.

As mentioned, A2 achieved a low PDE-CC extent in terms of engagement and productivity. Evidence suggests *problematizing*, *epistemic authority*, and *disciplinary* *accountability* were not incorporated while evidence for *resources* was not observed during A2's critique activity. A2 members frequently engaged in off-task talk instead of the poster critique activity. Much of their off-task talk involved a math test all students had taken prior to the critique activity. However, the test was not mentioned as much in the other groups' discourse. Although students in all the groups had taken the test prior to the critique activity, it is possible the test only affected A2 significantly to distract them but not other groups from their critique activity.

For Class B, the main difference in B1 and B2's PDE-CC extents is B2 achieved a slightly lower engagement level (i.e., information-seeking) than B1. This is likely due to similar extents to which the four PDE-CC guiding principles were incorporated in both groups' poster critique activity. *Problematizing* was not incorporated in B1 and B2's critique activity as both groups initially looked for the best poster and highlighted only positive aspects of their selected posters. Class B students only started searching for errors in their selected posters upon Ms. Lee's request. *Epistemic authority* was not shared among students and teachers. During her interaction with B1, Ms. Lee demonstrated higher *epistemic authority*. After asking B1 why they did not select the other posters and listening to Norman and Ariel's critiques of two unselected posters, Ms. Lee added to Norman's critiques, which was followed by Norman repeating Ms. Lee's critiques. During B1's "critical discussion" as abovementioned, Varun's successful refutation of Norman's critique was met by Ariel's condescending remark asking if Varun thought he was "very smart". This suggests Ariel did not recognize Varun's authority to critique, and epistemic authority was not considered shared among B1 members. For *disciplinary accountability*, Ms. Lee mostly held students' critiques accountable for justifying their ideas and non-scientific criteria. On the other hand, students did hold peers' critiques accountable to scientific criteria, such as during B1's "critical discussion". A possible reason for this observation is that at the start of the poster critique activity, Ms. Lee, introduced a set of non-scientific criteria as a *resource* to help Class B students critique the posters. Criteria introduced by Ms. Lee include: (1) whether the poster is engaging/interesting to the audience and (2) how well the information is communicated. An additional criterion, (3) the poster design mentioned by Ariel was also endorsed by Ms. Lee. Lack of elaboration on what "poster design" meant made the criterion ambiguous. Based on Ariel's reference to "poster design" during B1's critique activity, it could mean design goodness or appeal. Thus, the critique criteria introduced by Ms. Lee as a poster critique resource emphasized the non-scientific "communication goodness" criterion and the poster's emotional or aesthetic appeal to the audience.

Overall, greater extents to which *problematizing*, *epistemic authority*, and *disciplinary accountability* were incorporated in A1's critique activity seem relevant for higher disciplinarity observed in A1 than Class B groups during scientific poster critique activity. *Resources* for poster critique was useful for Class A as SSCs are aligned with scientific criteria but problematic for Class B as non-scientific criteria were introduced by the teacher.

Conclusions and Implications

Findings suggest taking a critical stance toward scientific claims is not natural to students. While teachers held students accountable to justifying ideas, they do not necessarily emphasize epistemic criteria, as in the case for Class B. However, evidence from A1 where students were guided to use scientific soundness criteria suggests such critique resources improved critique practices in the science classroom. Findings from the scientific poster critique activity and previous Class A intervention lessons reported elsewhere (Ong, 2018) suggest the student-centered critique instruction which incorporated all four PDE-CC guiding principles—problematizing, resources, shared epistemic authority, and disciplinary accountability—supported A1's achievement of high group PDE-CC during the poster critique activity. Thus, A1 students demonstrated taking a critical stance as they engaged in critical discussions using scientific criteria. Conversely, B1's less disciplinary discourse is related to inadequate incorporation of PDE-CC guiding principles during their poster critique activity and prior teacher-centered critique instruction Class B students experienced.

The poster critique activity demonstrates an example of argumentation activity focused on the practice of critique rather than tools for construction i.e., critiquing scientific poster instead of how to construct a scientific poster. A1 students were capable of engaging in critical discussions around their critique using scientific criteria valued by scientific communities in a productive way, which corresponds to processes and goals of scientific argumentation. Therefore, findings suggest if the instructional goal is to develop students' critique practices and critical stance, emphasis should be placed on argumentation as a critique practice. Teachers should provide epistemic tools valued by scientific communities for critique (e.g., the SSCs), provide an authentic context for students to practice critiquing (e.g., the poster critique activity), and model critiques for students to emulate (Ford, 2008) without taking over the critic role (compare when Mr. Gan versus Ms. Lee modeled critique).

Research highlighted in this chapter contributes to the growing literature that recognizes the importance of critique practices (Henderson et al., 2015, 2018) and problematizing epistemic decisions around transforming measurements to data, to evidence, and to scientific explanations for natural phenomena (Duschl & Bybee, 2014; McNeill & Berland, 2017) as the way forward for school science argumentation research. As findings reported in this chapter suggest, looking at scientific argumentation through the lens of epistemic practice involving epistemic tool use in relevant context is a promising approach for developing students' productive disciplinary engagement in critique practices.

References

Berland, L. K., & Hammer, D. (2012). Students' framings and their participation in scientific argumentation. In M. Khine (Ed.), *Perspectives on scientific argumentation: Theory, practice and research* (pp. 73–93). Dordrecht: Springer Netherlands.

Chi, M. T. H., & Wylie, R. (2014). The ICAP framework: Linking cognitive engagement to active learning outcomes. *Educational Psychologist, 49*(4), 219–243.

Driver, R., Asoko, H., Leach, J., Scott, P., & Mortimer, E. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher, 23*(7), 5–12.

Duschl, R. A., & Bybee, R. W. (2014). Planning and carrying out investigations: an entry to learning and to teacher professional development around NGSS science and engineering practices. *International Journal of STEM Education, 1*(12), 1–9. https://doi.org/10.1186/s40594-014-0012-6.

Engle, R. A., & 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.

Ford, M. J. (2008). Disciplinary authority and accountability in scientific practice and learning. *Science Education, 92*(3), 404–423.

Grandy, R., & Duschl, R. A. (2007). Reconsidering the character and role of inquiry in school science: Analysis of a conference. *Science & Education, 16*(2), 141–166.

Henderson, J. B., MacPherson, A., Osborne, J., & Wild, A. (2015). Beyond construction: Five arguments for the role and value of critique in learning science. *International Journal of Science Education, 37*(10), 1668–1697.

Henderson, J. B., McNeill, K. L., González-Howard, M., Close, K., & Evans, M. (2018). Key challenges and future directions for educational research on scientific argumentation. *Journal of Research in Science Teaching, 55*(1), 5–18.

Jiménez-Aleixandre, M.-P., & Erduran, S. (2007). Argumentation in science education: An overview. In M. P. Jiménez-Aleixandre & S. Erduran (Eds.), *Argumentation in science education* (pp. 3–27). New York: Springer.

Kelly, G. J. (2016). Methodological considerations for the study of epistemic cognition in practice. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *Handbook of epistemic cognition* (pp. 393–408). New York: Routledge.

Kelly, G., Brown, C., & Crawford, T. (2000). Experiments, contingencies, and curriculum: Providing opportunities for learning through improvisation in science teaching. *Science Education,* 624–657.

Kelly, G. J., Druker, S., & Chen, C. (1998). Students' reasoning about electricity: Combining performance assessments with argumentation analysis. *International Journal of Science Education, 20*(7), 849–871.

Longino, H. E. (2002). *The fate of knowledge*. Princeton University Press.

Manz, E. (2015). Representing student argumentation as functionally emergent from scientific activity. *Review of Educational Research, 85*(4), 553–590.

McNeill, K. L., & Berland, L. (2017). What is (or should be) scientific evidence use in K-12 classrooms? *Journal of Research in Science Teaching, 54*(5), 672–689.

McNeill, K. L., & Krajcik, J. (2007). Middle school students' use of appropriate and inappropriate evidence in writing scientific explanations. In M. Lovett & P. Shah (Eds.), *Thinking with Data: Proceedings of the 33rd Carnegie Symposium on Cogniton* (pp. 233–265). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

McNeill, K. L., Lizotte, D. J., Krajcik, J., & Marx, R. W. (2006). Supporting students' construction of scientific explanations by fading scaffolds in instructional materials. *Journal of the Learning Sciences, 15*(2), 153–191.

Ong, Y. S. (2018). *Developing secondary school students' epistemic practices through student-centered critique in scientific inquiry*. (Doctoral Dissertation). Retrieved from https://etda.libraries.psu.edu/catalog/15039yuo103.

Ong, Y. S., Duschl, R. A., & Plummer, J. D. (2018). Students' critique of epistemic decisions in scientific inquiry. In O. Finlayson, M. E., S. Erduran, & P. Childs (Eds.), *Electronic Proceedings of the ESERA 2017 Conference. Research, Practice and Collaboration in Science Education, Part 7: Strand 7* (pp. 1015–1025). Dublin: Dublin City University. Retrieved from https://www.dropbox.com/s/dtoivuqc9f1mjx3/Part_7_eBook.pdf?dl=0.

Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argumentation in school science. *Journal of Research in Science Teaching, 41*(10), 994–1020.

Scardamalia, M., & Bereiter, C. (2003). Knowledge building. In Encyclopedia of education. (2nd ed., pp. 1370–1373). Macmillan Reference.

Walton, D. N. (1998). *The new dialectic*. Toronto: University of Toronto Press.

Yann Shiou Ong is a postdoctoral fellow at the National Institute of Education, Nanyang Technological University, Singapore. Her current research focuses on secondary students' epistemic practices in scientific inquiry, specifically how students engage in group critique and construction practices. She adopts the productive disciplinary engagement framework and its guiding principles to analyse classroom/group discourses and the corresponding instructional designs. While she takes a pragmatic approach to data analysis, her research questions have mostly landed themselves to qualitative methods such as discourse analysis. Her other research interests include scientific models and modelling, social metacognition, and learning progressions.

Richard Duschl his academic career is defined by collaborations and scholarly interactions with others in science education, learning sciences and science studies. There are 3 themes to his research: (1) How the history and philosophy of science can be applied to science education; (2) How the design of extended curriculum and teaching sequences can promote 'assessment for learning' instructional models, and (3) How argumentation and discourse frameworks help promote instruction-assisted development and science learning. An emerging theme of these scholarly efforts has been the development of teaching science as three-part harmony attending to conceptual, epistemic and social (critique and communication) learning goals.

Julia Plummer spent over a decade teaching children and adults in planetariums and other informal settings and has extensive experience teaching college-level introductory astronomy and science methods for preservice elementary teachers. Her research interests focus on how children and adults engage in scientific practices in the astronomy domain. This includes investigating formal (e.g., classrooms) and informal environments (e.g., planetariums and museums). Julia has also investigated the importance of spatial reasoning in the domain. Her research led to the development of astronomy learning progressions focused on explaining celestial motion phenomena and connecting observations of the current Solar System to its formation model.