Chapter 7
An Integrative Approach to Scientific Argumentation: Pedagogy and Technology Tenets of IASA

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Abstract IASA, which stands for "Integrative Approach to Science Argumentation," is a project that sought to augment the goals of science education by integrating scientific argumentation with conceptual learning within the lower secondary science curriculum. Bearing in mind the constraints that our science teachers might face within a content-packed syllabus, our team set out to develop a pedagogical model embedded with novel contextual tasks. These student tasks were aimed at developing argumentative skills, which encompassed data sense-making, evidence harnessing, options weighing, and reasoning and communicative skills, alongside content development. Multiple resources that constituted our IASA "toolkit" were developed over the course of the 2.5-year project to provide professional learning and support for science teachers keen in embarking on this pedagogical innovation. This chapter will outline the designs of our pedagogical model, digital platform, IASA toolkit, and professional learning model as well as explicate impact for students as an overview of the project's conceptualization and implementation.

7.1 Introduction

There have been widespread efforts in recent years to expand the goals of science learning. Science education scholars and policymakers are veering away from an exclusive emphasis on learning science concepts and science process skills (Bricker & Bell, 2008; NRC, 2013). They argue that, while these goals remain essential to science learning, there is a need to re-position young science learners as legitimate participants in the practices of science communities (Ryu & Sandoval, 2012). The recommendation is for school science to be framed not just as science-as-knowledge but as science-as-practice (NRC, 2012; Stroupe, 2014). The latter entails promoting

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authentic disciplinary practices in the classroom. One such practice of science is argumentation, which entails harnessing information and data in a principled and rational way, weighing multiple options objectively and critically, and communicating their choice in a clear and convincing manner (OECD, 2013). Student engagement in scientific argumentation prepares them beyond the classroom, towards becoming proficient problem solvers in everyday life and competent participants in broader discourses of a science-dominated, technology-driven society (Ryu & Sandoval, 2012).

7.2 Background

The current curricular mandate in Singapore schools to teach science as inquiry enjoins teachers to adopt teaching approaches that introduce leaners to the knowledge-building practices of science (Berland & Reiser, 2009; MOE, 2012). While scientific argumentation is clearly recognized in curriculum documents as essential to teaching science as inquiry (Zembal-Saul, 2009), notwithstanding its alignment with schools' current thrust to develop learners' twenty-first-century competencies (Osborne, 2010), it is not accorded in classroom practices the prominence it deserves (Sampson & Blanchard, 2012). In order to address this issue, we embarked on a project to develop and test a pedagogical model, which we called Integrative Approach to Structured Argumentation (IASA) that aims to improve Lower Secondary learners' skills in scientific argumentation. Based on this model, we designed three learning tasks that provided science learners the opportunity to craft well-reasoned scientific arguments following the Claim–Evidence–Reasoning (CER) framework (McNeill & Krajcik, 2008). Accomplishing the learning task involved having learners work through a scientifically oriented problem by interpreting authentic data, learning relevant scientific concepts, and applying these concepts to the problem in order to advance, substantiate, and argue for a claim. We also developed a web app as a technology-enhanced platform to support learners' engagement with the IASA pedagogical model.

7.3 Why Structured Argumentation?

Developing learners in scientific argumentation is a promising step towards re-focusing school science from mere conceptual instruction to acculturation to scientific practices (NRC, 2012). Argumentation, as one of the core practices of science, enables scientists to build up explanations, models, and theories about the world; it is a tool for generating and confirming scientific knowledge (Duschl, 2008). Similarly, in the science classroom, when learners engage in writing tasks that demand the use of data for substantiation of claims, they have the opportunity to engage in the social practice of using evidence to build scientific knowledge (Berland & Hammer, 2012; Sampson, Grooms, & Walker, 2011). Through constructing arguments, learners could come to a better appreciation of the processes and norms through which knowledge in science is built over time (Manz, 2015).

Learners benefit from engaging in argumentation in several interrelated ways. Constructing arguments can:

- enable learners to understand science concepts (Sampson & Blanchard, 2012). Arguing to learn requires them to know and critically apply scientific ideas as they make sense of data that they have generated themselves or collected from other sources (Osborne, 2010). Learners' understanding of science concepts is enriched as they shift from merely giving definitions to invoking actual, real-life instantiations of science concepts.
- change learners' view of doing school science as merely memory work. It introduces them to the view that science is a particular *way of knowing* the world around us, providing descriptions and explanations of phenomena based on methods that are agreed upon by the community of scientists. Argumentation, as an epistemic practice, provides opportunities for learners not only to learn science content that the syllabus requires but they also learn about the social context within and through which scientists generate knowledge (Bricker & Bell, 2008; Duschl, Schweingruber, & Shouse, 2007).
- enculturate learners to select, evaluate and communicate their ideas. A good scientific argument is one that is robustly supported by a set of ideas that have been carefully selected and critically examined. The process of arguing demands that learners learn how to communicate the ideas that support their argument in a persuasive manner (Berland & Reiser, 2009).
- provide a good exercise for logical reasoning (Kuhn, 2010). Such thinking is fostered when learners are asked to articulate why a particular data set is considered evidence for the claim or how a scientific concept can be applied to a problem.

7.4 Challenges in the Teaching of Structured Argumentation

Teaching scientific argumentation (SA) remains an exception rather than the norm of science classrooms globally (Berland & McNeill, 2010). Many reasons have been suggested to explain its rarity. Being a complex practice, teaching SA requires substantial new knowledge gain and understanding from science teachers (Zembal-Saul, 2009), who are likely to have very little prior experiences in this practice either from their educational or professional training. Teachers also face practical constraints such as the need to prepare students for assessments (Li, Klahr, & Siler, 2018), limited curriculum time and accountability pressures (Alozie et al., 2010; Sampson & Blanchard, 2012).

In addition to the above challenges, science teachers in Singapore also face other challenges that may or may not apply to other educational contexts. Although science as inquiry has been advocated for more than a decade in the lower secondary science syllabus, science content, rather than scientific practices, remains the main curriculum emphasis. The study by Kim, Tan, & Talaue (2013) is insightful of the challenges that our local science teachers are likely to encounter when teaching SA. Though the study was on the perception of teachers towards inquiry-based curriculum reform, the challenges identified in it are likely to hold true for the teaching of SA. These challenges include "students' readiness and abilities," "lack of class time," "confusion on the meaning of inquiry," "assessment conflicts," "lack of time for preparation," and "heavy content in the curriculum," "lack of content knowledge," "lack of community support," and "other concerns, such as class size, noise, and giving up power to students" (ibid. p. 301). Anecdotally, our conversations with science heads of departments and teachers also suggest that teachers encounter difficulties with supporting students in addressing data-based questions, which require students to utilize and apply given data from a range of scientific representations (e.g., table, graphs, charts, diagrams) to explain scientific phenomena or conclusions. Such questions entail skill-set from students similar to SA. Challenges pertaining to addressing data-based questions are thus likely to compound the challenges that teachers face in integrating SA into their instruction.

When designing the pedagogical model for incorporating SA into the local science classrooms, these challenges are taken into consideration to generate adequate buy-in from science teachers who have to shoulder the risks of disrupting their classroom routines in embarking on this rather arduous educational innovation with us. Such considerations can also better optimize sustainability in the implementation of the pedagogical innovations when researchers eventually leave the research sites as it seeks to address the theory-practice gaps between research recommendations and classroom interventions (cf. Windschitl, 2002).

7.5 Pedagogy: IASA Design

Of the numerous challenges likely to be encountered by the local science teachers, we focused primarily on the following: (1) content-heavy curriculum, (2) time constraints, and (3) teachers' limited experiences and knowledge of SA. We believe that tackling these three challenges is a stepping stone towards resolving other challenges as teachers pursue this pedagogical innovation in the long run. We describe the tasks and pedagogical model below to illustrate how we took the three challenges into consideration when developing the IASA design.

7.5.1 IASA Tasks

We generated a total of three tasks, one each for the three science disciplines (Biology, Chemistry, and Physics), as prototypes of argumentative tasks that incorporate several desired design features. These task features include (1) invoke the need for canonical science knowledge as demanded in the syllabus for its successful completion, (2) involve two or more claims that are plausible to students, (3) contain multiple sets of data in various representation forms that serve as evidence for determining among the possible claims, (4) set in an authentic everyday context with a specific target audience for the argument generated by students. The last feature is necessary to ensure that students construct arguments purposefully (Berland & McNeill, 2010).

The first task feature is particularly pertinent in tackling Challenge (1), as it ensures that our argumentative tasks address the content objectives in the syllabus that science teachers are obliged to address in their lessons. We engaged in regular intensive discussions with our participating teachers to ensure that the tasks, while complex and challenging, can be completed within the time frame of their scheme of work (Challenge 2). In considering Challenge (3), our task design is situated at the simplest end of the instructional context dimension outlined in Berland and McNeill (2010)'s learning progression of learners of SA. That is, our tasks involve closely defined questions, implicate no more than a handful of potential answers and contain a data set that is confined to appropriate data. We believe that this approach provides a gentler runway for our teachers to take flight with the integration of SA.

The three tasks developed are on Ecology, Chemical Change and Heat. The Ecology task exhorts students to explore the effectiveness of various mosquito control measures in the fight against dengue fever with consideration of the impacts of these measures on biodiversity conservation. The task on Chemical Change examines the nature of the changes that take place when a mysterious chemical, a highly versatile household product, is used for various purposes in our daily life. Lastly, students compare between several aquarium designs in terms of their energy efficiency for the task on heat.

7.5.2 The Claim–Evidence–Reasoning (CER) Framework

We adopted the CER framework (McNeill & Krajcik, 2012) to guide the process of SA. Its three-part structure—claim, evidence, reasoning—ensures that students attend to the essential components of a scientific argument. It is important to note that the use of CER in our IASA model is *not* intended to be an answering technique for test preparation. Rather, it serves as a frame for guiding students in thinking about what they know and how they come to know. This mode of thinking engages students in working with evidence and developing reasoning skills, disciplinary practices that are crucial in generating knowledge claims in Science. Through engaging in such practices, we hope to shift students from being passive consumers to assuming the role of active contributors and critics of scientific knowledge.

7.5.3 Pedagogical Model

Due to the nature of the tasks, we are concerned that teachers may use them only at the end of a lesson sequence as a means to consolidate students' learning of the content objectives. We consider such an approach as less ideal as students would have less opportunities to practice SA alongside learning the content. It would also defeat our original objective of transforming current teaching practices with the goals of engaging students in scientific practices and developing twenty-first-century skills, such as critical thinking and reasoning. To counter such tendency, we develop a pedagogical model with the tasks as cornerstone of the lesson sequence within which the associated content objectives are relevant. The model seeks to ensure that students engage with SA alongside content learning throughout the lesson sequence.

Figure 7.1 illustrates the three-phase pedagogical model that integrates SA and content learning. We describe below the main lesson activities that accompany each phase and how these activities correspond with the 5E inquiry model (Bybee et al., 2006).

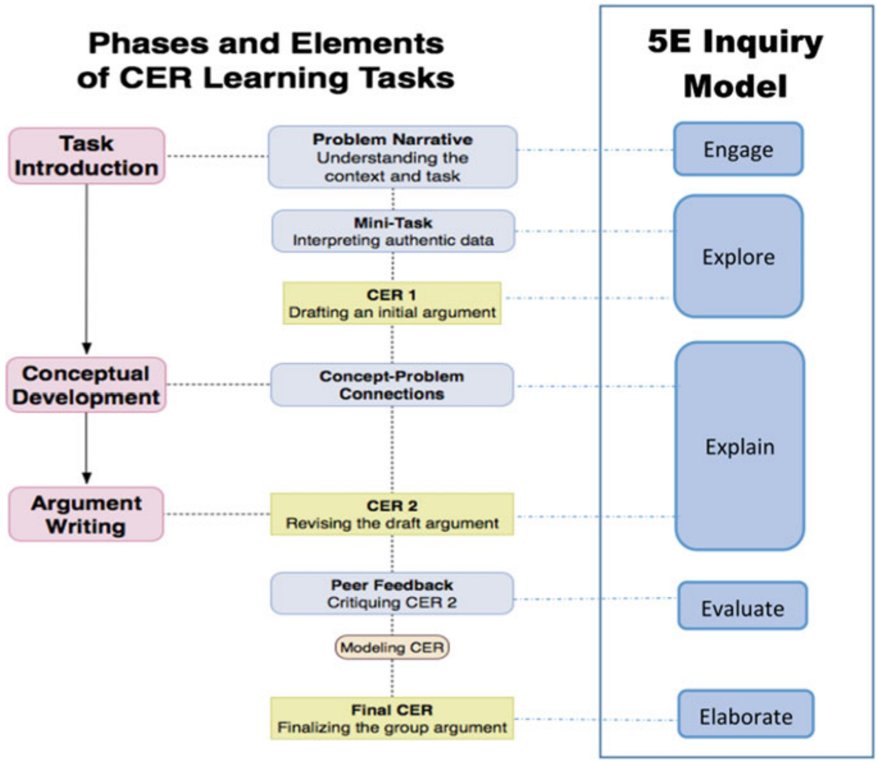

Fig. 7.1 IASA pedagogical model

Task Introduction. We propose introducing the task before any content introduction as a trigger for the topic. By providing an argument-driven context, the task prioritizes the process of SA over the accumulation of scientific facts (Driver et al., 1996). This phase comprises several activities. The first activity involves students familiarizing with and understanding the task. Being embedded in a narrative of a real-life scenario that simulate scientific investigations relevant to everyday life, the task serves to stimulate student interest in the topic and enables them to connect with their prior knowledge [5E: Engage]. The next two activities seek to build students' understanding of the phenomenon targeted in the task [5E: Explore]. Students are provided with mini-tasks to build their understanding of the context of the task and the multiple data sources. They are then asked to draft the first CER based on their initial rudimentary knowledge of the topic. Given the complexity of the task and their lack of canonical knowledge, students are unlikely to provide accurate and comprehensive argument at this stage. Nonetheless, this act of engaging students in crafting their CER1 is considered crucial in surfacing and mobilizing their prior knowledge and creating impasse that engender the impetus for students to attend to the relevant content knowledge in subsequent lessons (Kapur & Bielaczyc, 2012). Additionally, CER1 serves as a form of formative assessment, which offer teachers valuable insights into the extent of content knowledge and SA skills their students possess for the topic. The information gathered also allows the research team to provide contingent support to the teachers.

Content development. This constitutes the bulk of the lesson sequence during which teachers conduct lessons to address the content objectives [5E: Explain]. Two changes mark the difference between how teachers taught the topic previously and how they are encouraged to conduct this phase. One change involves making regular reference to the task by getting students to reflect on how the content knowledge taught can be applied to the task. To support teachers in this aspect, teaching materials containing reflection prompts were provided which teachers can adopt and adapt for their teaching purposes. These prompts draw students' attention to the connections between the content they learn to the task introduced to them in the beginning of the topic. This reflection process also encourages students to continuously review and revise their CER1 as they acquire new content knowledge and understanding of the topic that are relevant to the task. The regular referents to the task allow students to appreciate the relevance of the scientific concepts learned in solving everyday problems like those described in the tasks.

The second change involves teachers exploring opportunities within their teaching materials where CER can be applied. Teachers are encouraged to find instances of knowledge claim where evidence are available and to model how the CER structure can be applied to argue for the knowledge claim. Such modelling process illustrates to students how CER can be adopted to generate knowledge claims in science and increases their capacity to do the same for the task. In addition to the way teachers present scientific knowledge to students, changes were also made to learning activities. An example are the changes made to the practical activities for the topic on

Chemical Change. For this topic, students are typically required to conduct practical activities that involved testing the presence of carbon dioxide gas from reactions involving heating and the addition of acids. These practical activities presented opportunities to connect with the task which requires students to investigate the nature of a mysterious chemical. Instead of heating or adding acid to a known chemical, the practical worksheets were revised to allow students to test the effect of these changes on the mysterious chemical. Through the test for the presence of carbon dioxide gas, students are expected to deduce the nature of the mysterious chemical. Not only do the revised practical activities allow students to fulfil the original learning objectives, these activities now acquired an inquiry dimension that enables students to gather additional evidence that can be used for their CER construction in response to the task.

Argument refinement. With the completion of the content development phase, students return to the task to craft a new CER [CER2] based on the new understanding they acquire over the lesson sequence [5E: Explain]. To further support students in the process of SA, students' initial draft of CER2 are subjected to peer evaluation [5E: Evaluate]. Students are guided with a set of rubrics to evaluate and critique their peers' CER. The process of peer evaluation offers students opportunities to engage in the "utterance functions that are key to the argumentative process' such as "stating and defending claims," "questioning one another's claims and defense," "evaluating one another's claims and defense' and, "revising their own and other's claims." (Berland & McNeill, 2010, p. 776). With the feedback gathered, students can either improve on their individual CER or work together with a few peers to construct a group CER that synthesize the individual CERs into a coherent whole [5E: Elaborate]. Students are further guided with a set of question prompts prepared by the research team to guide them in formulating the group CER as students may need help with recognizing agreements, critiquing differing ideas, coming to a consensus and pulling ideas together, important skills for working in a team. Finally, teachers are encouraged to provide feedback to students on their CERs using the same rubrics as that used for peer evaluation.

Although group work tends to take up more time relative to individual work, group discussion serves an important role in the process of SA. Not only does group discussion enables students to consolidate the various data sources as evidence for their claim, students are also more likely to generate and appropriate persuasive discourse especially when disagreements arise, as students are compelled to generate arguments to convince opposing members to consider one's perspective. Such rehearsal of rhetoric could then be incorporated into their writing. It is worth noting that scientific knowledge is always generated by a community of scientists and participating in peer evaluation and group discussion reflect the real-life practices of scientists.

7.6 Technology: IASA Web Tool

To support the IASA pedagogical model, we developed a web-based integrated platform that affords students the ability and agency to harness scientific argumentation tasks that capture the core components of authentic science inquiry (Fig. 7.1). Recognizing that the epistemology of conventional scientific inquiry tasks (e.g., simple experiments, simple observations, and simple illustrations) may be antithetical to the epistemology of authentic science, the design of the IASA platform was underpinned by salient tenets of authentic scientific inquiry processes such as concept-problem connections, group deliberations and peer feedback. Areas of scientific content learning that were based on authentic scenarios drawn upon available authentic data at www.data.gov.sg, which students can subsequently easily utilize in their argumentative inquiry.

As indicated in Fig. 7.1, the sequence of the pedagogical process afforded by the web platform represents a knowledge building cycle (Leitão, 2000). First, learners are introduced to the problem narrative. They are then introduced to a set of mini tasks which aims to elicit prior conceptual construals that the students may already have which in turn, facilitate teachers' addressing of students' misconceptions, if any. Students then move on to participate in their first argument phase on the platform. By constructing arguments, it is intended that students' will self-explain the learning material and integrate new knowledge into their existing cognitive structures. Following argument construction, students can engage in group work to construct counterarguments in order to challenge the initial positions. Construction of counterarguments facilitates meta-cognitive activities and engages a rethinking of students' primary positions with a view to not only refining their initial position but so too in constructing integrative arguments to strengthen their argument narrative. The process of interweaving personal arguments and peer counterarguments in order to solve the authentic problem set out in the task narrative affords learners with not only the development of argumentation competency, but also domain specific knowledge of the content under consideration (Leitão, 2000), in this case scientific understanding related to the selected topics.

7.6.1 Features and Affordances

The IASA platform is designed to facilitate teachers' pedagogical repertoire in science teaching, specifically in being able to enact the IASA model effectively. Specifically, apart from identifying potential difficulties teachers may experience during the face-to-face teaching, and subsequently designing for how technology can mitigate the identified face-to-face difficulties, we were cognizant that the introduction of technology tools for Science need to meaningfully augment teaching and learning to meet both teachers' and learners' needs.

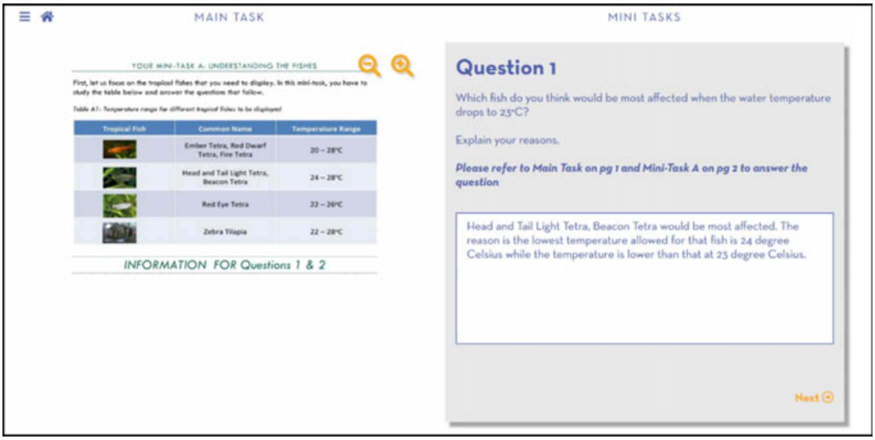

Fig. 7.2 Dual panel interface

7.6.1.1 Overarching Interface: Dual Panel to Mitigate Cognitive Load

The teaching of a scientific topic anchored by an argumentation and inquiry pedagogical orientation entails harnessing multiple resources in its enactment. For example, in teaching a topic such as heat and its related concepts, teachers make use of multiple teaching resources which include include tasks narratives, PowerPoint slides and data sheets. At an overarching level, the IASA platform interface is designed as a dual panel view (see Fig. 7.2) where both teachers and students will be able to easily reference supplemental materials provided at the respective pedagogical stage.

In Fig. 7.2, students are able to reference the heat task on the right pane, scrollable from the introductory narrative to the data source examples. In attempting the mini tasks on the left pane, students are able to easily reference data sets and question options within a single screen view. At the core of such an affordance is an instructional design schema aimed to mitigate cognitive overload in facilitating relations between source and questions, through the use of technology (Sweller, 1988). Table 7.1 further details how the dual panel interface frames the pedagogical process and activities within the IASA platform, elaborating on the functionality that mediates both left and right panels.

As seen from Table 7.1, the pedagogical processes in Fig. 7.1 is not only mirrored in the development of IASA's web platform, but more importantly, the development of the platform is underpinned by desired affordances of technology to mitigate challenges in integrating scientific argumentation with conceptual learning. The designed affordances included the IASA tool:

- As diagnostic assessment:
  - Wherein students will experience the process of unpacking task complexity which includes activation of students' prior knowledge

Table 7.1 Activities and displays information with default pedagogical process flow shown

Activities [Right Panel]	Functionality	Displays [Left Panel]	Functionality
Main Task [Full Display]	Shows the main task question of the lesson and information materials	N/A	N/A
Mini tasks	Answering MCQ/Structured Questions Form where only one question will be shown at a time MCQ questions have to be answered correctly where each wrong choice the student will be provided a feedback	Main task	Same as previous lesson stage for referencing of information regarding questions
First CER	Answering an Individual CER form, which consists of a Claim Question, Evidence Question and a Reasoning Question. Allowed to Save Progress	Infosheet	Shows student's answers to the mini tasks' questions' answers Additional information if the lesson has it
Group pool	Viewable First CER answers from the members of the student's group Allows changing of current answer to any group member's answer including oneself	Infosheet	Same as previous lesson information except that model answers to the structured questions are shown
Concept linking	Answering MCQ/Structured Questions Form where only one question will be shown at a time	Concept slides	Teacher's lesson slides
Second CER	Improving on First CER answers with new information provided Allowed to Save Progress	Concept linking answers	Shows student's concept linking questions and answers
Feedback	Providing feedback to members of the student's group Second CER answers Allow feedback to each group member's answer except oneself	Your second CER	Shows student's Second CER answer

(continued)

Table 7.1 (continued)

Activities [Right Panel]	Functionality	Displays [Left Panel]	Functionality
Final CER	Collaborative CER Form to allow group members to work together to answer the main question of the lesson which includes the Claim, Evidence and Reasoning Questions in previous CER forms	Group pool feedback	Show group members' feedbacks towards other members' Second CER answers Allowed to provide more feedbacks and refresh to get latest feedbacks
		Group pool table	Show group members Second CER answers in a table comparison format

- As formative assessment:
  - Wherein students are likely to use their everyday experience and intuitive knowledge during their initial experience with the task. This allows teachers to access their prior knowledge and possible misconceptions
- As learning analytics:
  - Wherein the tool is able to capture the group CER process. Such collaborative processes are hard to track and capture in face to face settings. Using the tool, teachers are able to track and analyze students' progress in a timely manner as the topic is being taught over the planned period of time in a formative fashion, vis-à-vis tracking of students' progress via workbooks only at the end of the topic.

7.7 Teacher Apprenticeship in IASA Pedagogy

The research team partnered participating teachers in an apprenticeship fashion where teachers were engaged in context setting of the value of scientific argumentation for conceptual learning. The aim of the researcher–practitioner partnership was to facilitate teachers' development as being "peripheral participants" in IASA pedagogy towards being a more central enactor of IASA. Research papers highlighting the importance and value of scientific argumentation were shared with teachers and time was spent in discussing pertinent issues related to science teaching and learning. Teachers were introduced to the tasks—for instance, while the first task on Heat was primarily researcher-driven, it also sets the pathway as an initial model for teachers to "be apprenticed" to how authentic, inquiry oriented tasks may be developed and anchored for the teaching of Science topics. Subsequently the development of the

Fig. 7.3 Teacher interface of IASA Web App

Chemistry and Biology tasks were teacher-driven as teacher participants grew into more central roles in designing for their IASA classroom enactments. Teachers were also introduced to the IASA web tool, where its functionality and affordances were introduced and explained. A hands-on session for the IASA tool was also conducted with the teachers and feedback from their use was subsequently taken into account in the research team's refinement of the platform. A teachers' interface of the IASA web tool was also developed to further catalyze teachers' apprenticeship development towards using the IASA pedagogy in their classroom. The teachers' interface was designed for teachers to be able to formatively assess each students' progress through the development of the topic they were teaching, as indicated by the underlying analytics of the tool. These included the functionality to (i) have an overview of the progress of students, both at the individual and class level based on the IASA pedagogical cycle, (ii) have a quick understanding of students' prior understanding, beliefs about the topic based on their response to the mini-quiz, (iii) have an overview of the group and individual scientific argumentation discourse and the types of feedback exchanged between group members, iv) identify keywords used by students in their CER responses (see Fig. 7.3).

7.8 Impact on Teacher Development

Our sustained engagement with teachers in this research project provides one possible professional development (PD) model for the induction of in-service teachers to an argument-based pedagogy. This PD model consists mainly of: (1) collaborative joint development and/or refinement of the learning tasks; (2) sustained and detailed assessment of students' personal resources for engaging in explanation-driven inquiry (Mikeska, Anderson, & Schwarz, 2009; Zembal-Saul, 2009); and (3) critical reflection on the enactment of the IASA pedagogical model.

Through our collaborative activities for developing the learning tasks, teachers learned how to situate science learning within everyday contexts, as exemplified in the argumentation tasks that were embedded with real-life scenarios. Teachers learned that positioning the argument-based learning task as the central and unifying frame for their teaching afforded foregrounding the relevance of science concepts to real life problems. For example, one teacher remarked: "Because I usually like to bring in (a task) after they have learned the whole concept, then they will be able to see a bigger picture. *But I was thinking maybe we can also try to set it as a trigger to cover what we need to cover … So give them an end in mind. So maybe that could have worked also.*." Despite her initial reservation, the teacher was willing to adopt the task as the central focus of the lesson unit. Such problem-based framing allowed teachers to appreciate science teaching and learning as contextualized and, as such, promotes leaners' interest in and motivation for the lesson. One teacher appreciated the approach we adopted as a concrete example of how teachers can infuse science classrooms with "authentic learning" experiences (Watkins, Coffey, Redish, & Cooke, 2012).

With respect to integrating the practice of argumentation in science lessons, discussions during the curricular development meetings coupled with actual classroom implementation helped teachers gradually understand the various dimensions of the CER framework and how they can be surfaced during lessons. It helped them be aware of and appropriately use teaching prompts for drawing out more reasoned explanations from students (Avraamidou & Zembal-Saul, 2005). Teachers enacted verbal scaffolds as students examined data for patterns, as well as when they substantiated, compared, and evaluated claims. Using teaching slides and reflection logs in science notebooks, teachers also engaged learners to make explicit any emerging understandings of how their argument claim in the learning task is linked to the science concepts they were learning.

Our PD model created a platform for teachers to assess students' ideas and language competencies, and their varying levels of engagement with the learning tasks so that appropriate modes of instructional support could be developed collaboratively and implemented (Zembal-Saul, 2009). Teachers valued our collaborative discussions of students' ideas on a topic because it allowed them to anticipate, identify, and address misconceptions in class. Additionally, assessment of students' language competencies helped teachers refine the language in teaching and learning resources.

We engaged teachers in post-lesson dialogs to facilitate critical reflection on their own development as a teacher who promotes scientific argumentation (Zembal-Saul, 2009). We tapped on the challenges and learning points teachers experienced during classroom enactment to facilitate contextualizing the adoption of the IASA model. One persistent concern among teachers was a felt tension between promoting argumentation while aiming to achieve the specified learning outcomes stipulated in the syllabus (Kapon, Laherto, & Levrini, 2018; Kim et al., 2013). For instance, one teacher observed how some students may appreciate scientific argumentation more "i*f the exam had a CER component… [or] if it is part of the curriculum itself*." Despite this concern, most teachers have come to appreciate the value added by our teaching intervention—that students began to better appreciate science concepts in terms of their relevance to everyday experiences and engage in deeper learning of these concepts.

Overall, we believe that our partnership with the teacher participants engendered a sense of ownership (Danielowich, 2007) of the IASA model that could inspire continued adoption and future scaling up to more science classrooms. Moreover, teachers' use of the IASA Web App as a technology-enhanced platform integrated to the pedagogical model helped them promote the tenets of the macro educational policy aims, specifically self-directed learning, collaborative learning and authentic learning as mediated by technology.

7.9 Impact on Student Learning

To assess the impact of teachers' enactment of the IASA pedagogical model on student learning, we analyzed changes in the quality of students' written arguments. With the CER framework and a complementary assessment rubric (i.e., the criteria for good scientific argumentation that teachers elaborated on during instruction), students had a simple and structured guide for attending to the essential qualities of a written scientific argument. We scored the extent to which students brought off the qualities of good scientific argumentation in their individually written arguments (CERs), noted change patterns across the multiple intervention cycles.

In addition, our assessment of impact on student learning included an analysis of students' awareness of the criteria by evaluating the quality of students' feedback on their group mates' draft arguments. We looked out for features of argument writing that were salient in students' feedback and noted any changes in the kind of feedback given across two intervention cycles. Students' feedback was captured using the IASA web app which allowed asynchronous chat among group mates.

7.9.1 Increased Attention to Evidence and Scientific Reasoning

The results of the analysis indicate that the quality of written arguments, on average, improved over the course of the intervention. This is evidenced by the increase in average scores for all argument component from the initial to the final writing samples (Table 7.2). The two argument components with the highest increase in average scores are: (1) students' use of evidence and (2) appropriate language use for scientific reasoning. We found an increase in students citing data for evidence,

Table 7.2 Comparison of the average scores of argument components between initial and last individual written arguments of experimental class

Components	Max score	Initial CER SQ[a], n = 28	Final CER heat Task, n = 34	% Change
Claim	2	1.9	1.9	0.0
Evidence	7	3.0	4.6	22.9
Reasoning	9	6.1	6.4	3.3
Language use	5	3.2	3.9	14.0
Total score	23	14.2	16.8	11.3

[a]The structured question (SQ) is a written argument task used to provide baseline information on students

mobilizing relevant data, and making counterarguments (i.e., comparing across claim options). We also noted an increase in the number of students providing more accurate and relevant reasoning, along with considerable improvement in the appropriate and extensive use of scientific language in their arguments. However, some aspects of scientific reasoning need more instructional attention. For example, most students simply explained the effects of each variable they identified, while a few others clearly elaborated on interrelated effects of multiple variables they considered (Table 7.2).

The above results suggest that with multiple exposure to the task of writing arguments, students gradually appropriate the criteria and conventions for good scientific argumentation (Berland & Reiser, 2009). This was facilitated by teachers' explicit instruction of the ways students could satisfy the criteria. Teachers used the rubrics for a good scientific argument as a heuristic to aid student in complying with the conventions and judging evidence reasonably. The improvement in the quality of students' reasoning in offering valid arguments may also be due to the conceptual instruction that was provided. Conceptual instruction equipped them with the appropriate knowledge resources for making sense of the data and using the appropriate data as evidence for their claim (Grooms, Sampson, & Enderle, 2018; Osborne, 2010).

7.9.2 Improved Peer Feedback During Argument Revision

During argument feedback sessions, we anticipated that students might simply deploy positive and negative assessments (such as compliments and criticisms) without providing their reasons. Some students might be able to give a reasoned critique (based on the rubrics they were asked to use) that could focus on inaccuracies in scientific concepts used, erroneous data interpretation, illogical inferences, insufficiencies in terms of supporting evidence, etc. Others might focus on language errors and incorrect composition formats.

Our analysis noted a decrease in the number of students not giving any feedback across the two learning cycles (Table 7.3). This is a positive outcome as it indicated increased participation in the peer feedback activity. We also found that, in general, students deployed more positive feedback than critical feedback. There was greater tendency among students to give positive feedback that is non-specific or merely citing criterion without justification. In terms of positive feedback across the two activities, there was a decrease in non-specific feedback along with an increase in explained, criteria-based feedback. This indicated that more students have become aware that feedback needs to be specific and reasoned, a point that was emphasized by teachers during instruction.

We found mixed results with respect to critical feedback. There was an increase in the non-specific type that indicates either decreased attention to or emphasis on the proper application of criteria or opting for the convenience of unelaborated feedback. The latter seems to be the case because during the group feedback session for Heat, students experienced weak wi-fi connectivity in the classroom leading to non-completion of the task during the science period. Students were asked to complete the task during free time outside class or at home. Such technical challenge was absent during the Acids group feedback session, which was completed within the class period. The results for critical feedback also show only a slight increase in criteria-based, explained feedback along with a decrease in criteria-based, mentioned only feedback. Nevertheless, critical feedback that targeted specific features of the argument far outnumbered the nonspecific ones, indicating more students being aware of criteria dimensions in deploying their critique.

These findings suggest that sustained engagement in peer feedback activity improves the quality of feedback as students experienced greater awareness of the writing requirements for good scientific argumentation (Berland & McNeill, 2010). Peer feedback activity provided students the opportunity to reflect on their own

Table 7.3 Relative frequencies of peer feedback categories

Category	Sub-category	Acids task (%)	Heat task (%)
No feedback		14.4	2.8
Positive		45.0	43.1
Nonspecific		*19.2*	*11.1*
Criteria-based	*Explained*[a]	*3.4*	*9.7*
	Mere mention	*22.3*	*22.2*
Critical		39.9	40.3
Nonspecific		*4.1*	*8.3*
Criteria-based	*Explained*[a]	*30.9*	*31.9*
	Mere mention	*4.8*	*0.0*
Format		0.7	0.0

[a] Students provided an assessment that elaborates how the relevant criterion is satisfied (positive/critical feedback) or not satisfied (critical feedback) in their peers' argument

writing in terms of how it compares to their peers' arguments, as some shared during the student interviews. The findings also suggest that teachers need to guide and model how student feedback can be made more specific and reasoned. Explicit teaching of the criteria for good scientific argumentation could increase students' awareness of good quality scientific arguments and could lead to appropriation of critical thinking in their own writing (Manz, 2015; Osborne, Erduran, & Simon, 2004). The practice of argumentation in the classroom introduced students to how scientific knowledge is negotiated and engaged them in science discourse.

7.10 Scaling Up IASA

Schools who are interested in adopting an argument-based pedagogy for their Lower Sec science classes can use the IASA pedagogical model. A lesson package—the IASA Toolkit—which contains all the resources for the three learning tasks we have developed is ready for dissemination. The resources include lesson plans, worksheets, sample teacher talk for integrating CER and learning task, sample CERs written by students, and teaching slides. Resources for conducting student workshops on the CER framework are also available. The IASA Web App with its affordances can also be accessed to support students' argument writing tasks and teachers' logistical work.

It is, however, critical to first engage teachers in conversation about the underlying rationale and principles of the model and provide a forum for sharing on-the-ground experiences in implementing the pedagogical innovation (Osborne et al., 2004). While this initial conversation will be helpful in getting teachers started, we believe what would be more beneficial is to have teachers implement the innovation and sustain conversations about the questions, issues, and dilemmas such implementation raises about established practices, not only for pupil learning but also for the school as a learning organization. An evidence and argument lens for teaching could inform how teachers track and analyze student thinking in the classroom as they write and talk science (Zembal-Saul, 2009). However, learning to adopt such lens is not a short-term, linear process of improvement with immediate results. In our view, the teacher-collaborators we worked with took up the new initiative in varying degrees within equally varying time periods: some persistently struggled to work around institutional expectations, while others took up ownership quite quickly, having a clear view of the spaces in the classroom to inject reform. Regardless of their individual learning pace, we found it important to trust them in the validity of their own decision-making around its direction. We acknowledge that their current practice is the only available starting point, and that any change they embrace must make sense to, and benefit, them as individual learners, and not only their students or their school (Czerniawski, 2013).

Sustaining the adoption of the pedagogical innovation will rely heavily on the buy-in of the project's ideals by the participating teachers as well as the school leadership, since the school workplace is the immediate practice setting. In our experience, we found alignment with our participating schools' educational advocacy—Authentic Learning in Science for one school and Critical Thinking for another school. This alignment allowed for a partnership to be forged easily to achieve complementary goals. However, such matching is not outrightly a success formula for the adoption of new initiatives. We can ask, following the ideas of Grossman et al. (2009), can the school also provide a safe, low-risk setting for reform-oriented teachers to acquire and practice diverse pedagogical skills?

Further research will be needed to test the feasibility and efficacy of the pedagogical approach if and when adopted to science classes in primary schools and Upper Secondary Schools.

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References

Alozie, N.M., Moje, E.B., & Krajcik, J.S. (2010). An analysis of the supports and constraints for scientific discussion in high school project-based science. *Science Education*, *94*, 395–427. https://doi.org/10.1002/sce.20365

Avraamidou, L., & Zembal-Saul, C. (2005). Giving priority to evidence in science teaching: A first-year elementary teacher's specialized practices and knowledge. *Journal of Research in Science Teaching*, *42*(9), 965–986. https://doi.org/10.1002/tea.20081

Berland, L., & Hammer, D. (2012). Framing for scientific argumentation. *Journal of Research in Science Teaching*, *49*(1), 68–94. https://doi.org/10.1002/tea.20446

Berland, L., & McNeill, K. L. (2010). A learning progression for scientific argumentation: Understanding student work and designing supportive instructional contexts. *Science Education*, *94*(5), 765–793. https://doi.org/10.1002/sce.20402

Berland, L., & Reiser, B. J. (2009). Making sense of argumentation and explanation. *Science Education*, *93*(1), 26–55. https://doi.org/10.1002/sce.20286

Bricker, L. A., & Bell, P. (2008). Conceptualizations of argumentation from science studies and the learning sciences and their implications for the practices of science education. *Science Education*, *92*(3), 473–498. https://doi.org/10.1002/sce.20278

Bybee, R., Taylor, J., et al. (2006). *The BSCS 5E instructional model: Origins and effectiveness.* Colorado Springs, CO: BSCS.

Czerniawski, G. (2013). Professional development for professional learners: Teachers' experiences in Norway, Germany and England. *Journal of Education for Teaching*, *39*(4), 383–399. https://doi.org/10.1080/02607476.2013.769339

Danielowich, R. (2007). Negotiating the conflicts: Reexamining the structure and function of reflection in science teacher learning. *Science Education*, *91*(4), 629–663. https://doi.org/10.1002/sce.20207

Driver, R., Leach, J., Millar, R., & Scott, P. 1996. *Young people's images of science*. Philadelphia: Open University Press.
Duschl, R. A. (2008). Science education in three-part harmony: balancing conceptual, epistemic, and social learning goals. *Review of Research in Education*, *32*(February 2008), 268–291. https://doi.org/10.3102/0091732X07309371
Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. (Eds.). (2007). *Taking science to school: Learning and teaching science in grades K-8*. National Academies Press. Retrieved from https://books.google.com.sg/books?id=qMJVAgAAQBAJ
Grooms, J., Sampson, V., & Enderle, P. (2018). How concept familiarity and experience with scientific argumentation are related to the way groups participate in an episode of argumentation. *Journal of Research in Science Teaching*. https://doi.org/10.1002/tea.21451
Grossman, P., Compton, C., Igra, D., Ronfeldt, M., Shahan, E., & Williamson, P. (2009). Teaching practice: A cross-professional perspective. *Teachers College Record*, *111*(9), 2055–2100.
Kapon, S., Laherto, A., & Levrini, O. (2018). Disciplinary authenticity and personal relevance in school science. *Science Education*, *102*(5), 1077–1106. https://doi.org/10.1002/sce.21458
Kapur, M., & Bielaczyc, K. (2012). Designing for productive failure. *Journal of the Learning Sciences*, *21*(1), 45–83. https://doi.org/10.1080/10508406.2011.591717
Kim, M., Tan, A. L., & Talaue, F. T. (2013). New vision and challenges in inquiry-based curriculum change in Singapore. *International Journal of Science Education*, 1–23. https://doi.org/10.1080/09500693.2011.636844
Kuhn, D. (2010). Teaching and learning science as argument. *Science Education*, *94*(5), 810–824. https://doi.org/10.1002/sce.20395
Leitão, S. (2000). The potential of argument in knowledge building. *Human Development, 43*(6), 332–360.
Li, J., Klahr, D., & Siler, S. (2018). *What lies beneath the science achievement gap: The challenges of aligning science instruction with standards and tests (Version 1)*. Carnegie Mellon University. https://doi.org/10.1184/R1/6619106.v1
Manz, E. (2015). Representing student argumentation as functionally emergent from scientific activity. *Review of Educational Research*, *85*(4), 553–590. https://doi.org/10.3102/0034654314558490
McNeill, K. L., & Krajcik, J. (2008). Inquiry and scientific explanations: Helping students use evidence and reasoning. In J. A. Luft, R. L. Bell, & J. Gess-Newsome (Eds.), *Science as inquiry in the secondary setting* (pp. 121–134). Arlington: NSTA Press.
McNeill, K. L., & Krajcik, J. (2012). *Supporting grade 5–8 students in constructing explanations in science: The claim, evidence, and reasoning framework for talk and writing*. New York: Allyn and Bacon
Mikeska, J. N., Anderson, C. W., & Schwarz, C. V. (2009). Principled reasoning about problems of practice. *Science Education*, *93*(4), 678–686. https://doi.org/10.1002/sce.20312
MOE. (2012). Science Syllabus Lower Secondary: Express Course, Normal (Academic) Course. Ministry of Education—Singapore.
NRC. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: The National Academies Press. https://doi.org/10.17226/13165
NRC. (2013). *Next Generation Science Standards: For states, by states*. Washington, DC: The National Academies Press. https://doi.org/10.17226/18290
OECD. (2013). *Trends shaping education 2013*. Retrieved from https://www.oecd-ilibrary.org/content/publication/trends_edu-2013-en
Osborne, J. (2010). Arguing to learn in science: The role of collaborative, critical discourse. *Science*, *328*(5977), 463–466. https://doi.org/10.1126/science.1183944
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. https://doi.org/10.1002/tea.20035

Ryu, S., & Sandoval, W. A. (2012). Improvements to elementary children's epistemic understanding from sustained argumentation. *Science Education*, *96*(3), 488–526. https://doi.org/10.1002/sce.21006

Sampson, V., & Blanchard, M. R. (2012). Science teachers and scientific argumentation: Trends in views and practice. *Journal of Research in Science Teaching*, *49*(9), 1122–1148. https://doi.org/10.1002/tea.21037

Sampson, V., Grooms, J., & Walker, J. P. (2011). Argument-Driven Inquiry as a way to help students learn how to participate in scientific argumentation and craft written arguments: An exploratory study. *Science Education*, *95*(2), 217–257. https://doi.org/10.1002/sce.20421

Stroupe, D. (2014). Examining classroom science practice communities: How teachers and students negotiate epistemic agency and learn science-as-practice. *Science Education*, *98*(3), 487–516. https://doi.org/10.1002/sce.21112

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning, *Cognitive Science*, *12*, 257–285.

Watkins, J., Coffey, J. E., Redish, E. F., & Cooke, T. J. (2012). Disciplinary authenticity: Enriching the reforms of introductory physics courses for life-science students. *Physical Review Special Topics—Physics Education Research*, *8*(1), 010112. https://doi.org/10.1103/PhysRevSTPER.8.010112

Windschitl, M. (2002). Framing constructivism in practice as the negotiation of dilemmas: An analysis of the conceptual, pedagogical, cultural, and political challenges facing teachers. *Review of Educational Research*, *72*(2), 131–175.

Zembal-Saul, C. (2009). Learning to teach elementary school science as argument. *Science Education*, *93*(4), 687–719. https://doi.org/10.1002/sce.20325

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