What's Worth Solving? An Expert Study to Identify Problem-Finding Strategies within a Socio-Scientific Issue

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Abstract: A problem becomes an investigation's point, leading to the incremental construction of new knowledge and contributing to a broader problem-solving procedure. Often, it is identified through observation, research through literature, or suggested by a teacher. However, little is known about how problem finding (PF) can be developed as a strategic skill within educational settings. Thus, this article aims to understand the high leverage processes required to do PF. We use socio-scientific issues (SSI) as a meaningful context for its complexity and ethical nature. Thus, a case study involving three STEM domain experts is used to understand the processes required to negotiate a controversial SSI. Findings indicate that strategic use of collaborative argumentation and socio-scientific reasoning competencies can facilitate finding problems worth solving.

Introduction

Problem-solving has always been a highly focused research line. However, not enough focus is given on whether learners have the skills to find problems. Indeed, the first step of solving a problem is recognizing that there is one. Hence, in this article, our objective is to understand the process of problem finding (PF).

Learners are motivated to solve real-world and impactful problems through a science fair project or an extensive Ph.D. dissertation. For instance, within educational settings, problem-based learning attempts to make learning meaningful by engaging learners through socio-scientific issues (SSI) (Sadler, Barab, & Scott, 2007). SSI are complex social issues such as COVID-19 with embedded science content. Any efforts to resolve them require multiple perspectives, ranging from the scientific subject matter, ethical considerations, moral values, policy, and citizenship. While solving these complex issues as a whole is unrealistic, finding operational and solvable minor problems within them can be done. Thus, in this article, SSI is taken as a context for problem finding.

Popularly, 'problems present themselves' is a common idea that precedes a problem-solving procedure. However, problems need to be unearthed in complex issues like SSI to address them comprehensively. To illustrate, here we show how PF can look within an SSI. In 2017, the Government of India initiated the countrywide measles and rubella vaccine campaign. However, several schools refused to allow health officials to vaccinate students citing misinformation spread through WhatsApp (a popular messaging app). Local health officials were not sufficiently prepared to address this problem. News reports found that the media content within these anti-vaccine messages was linked to several US-based YouTube channels. In hindsight, it seems reasonable that misinformation content that had caused widespread panic in the West could make its way to thwart vaccination efforts in India. The problem could have been predicted before the campaign was in full swing. In this case, an embedded problem is identified. It is not symptomatic or immediately evident. Given its novelty, it can be a great starting point for learners to explore the effects of social media-based misinformation. Motivated by such instances, our goal is to understand and unpack the high leverage skills and processes required to do problem finding within an SSI.

Literature

Problem Finding

The ability to find problems is defined as a family of related skills involving problem identification, problem definition, problem construction, and problem expression (Abdulla, Cramond & Runco, 2018). In this article, we consider the definition of problem-finding as the 'ability to imagine, look for discrepancies and apparent contradictions, and entertain new hypotheses about old problems/issues or generate entirely different questions or problems to be solved' (Runco, 1994).

Studies in science education research have focused on students' formulation of feasible questions for empirical testing (Chin & Osborne, 2008). Lee and Cho (2007) examined the factors affecting problem-finding depending on the problems, such as ill-structured situations. The typical process of being dependent on a teacher for providing a functional problem may deprive the learners of practice in the iterative steps required to understand, analyze, and define a problem (Steiner, 2014). Hence, it is crucial to establish problem-finding as a specialized learning activity. Also, PF skills feature within teacher education practices for constructing 'big ideas' as contexts for facilitating science instruction through problem or project-based learning (Windschitl et al., 2012). This teaching practice is crucial for building a solid foundation for jumpstarting complex learning processes, whether through collaboration or inquiry. In another study, learners navigated through a problem-solution framework to identify social problems within their community (Chang et al., 2004). Researching how to initiate learners to systematically and independently self-direct their focused projects is an active topic of interest.

Specific to SSI-based instruction, the complexity surrounding science content which can range from ethics, personal values, to social and political aspects, makes it challenging to implement. Educators have identified the need for new pedagogical frameworks to foster learner-led engagement (Yoon, 2008). However, learners' self-generated inquiry ideas may be the most encouraging to ensure sustained interest. Given the complexity of an SSI, there is a need to explore the various processes required to find a focused and purposeful problem worth solving. One way to identify crucial and ideal processes is to do expert modeling, wherein a subject matter expert demonstrates the processes required to engage in a specific skill (Belland, Kim, & Hannafin, 2013). Hence, our motivation is to understand how subject matter experts do problem finding. While it has been studied in the context of creativity and science inquiry, little is known about the practices or skills that can facilitate it in an SSI instruction setting. The research discussed in this paper is guided by the question: *What strategies subject-matter experts employ for doing meaningful problem-finding within an SSI?*

Problems worth solving: Problem finding and Socio-scientific issue-based instruction

Learning gains associated with SSI include higher-order cognitive processes such as critical thinking, decision-making, formal and informal reasoning, and argumentation. Socio-scientific reasoning (SSR) has been developed to examine the complex associated student learning goals. It consists of a set of interlinked competencies such as accounting for the inherent complexity of SSI, analyzing issues from multiple perspectives, identifying aspects of issues that are subject to an ongoing inquiry, and employing scepticism in the analysis of potentially biased information (Sadler, Barab, & Scott, 2007). SSI literature shows potential for enacting the requirements required for problem-finding. The intersection between the two literature bodies of problem-finding and SSI-based instruction is visualized within the themes of inquiry, intrinsic motivation, perspective-taking, and collaboration.

Problem-finding studies suggest employing open-ended questions to investigate a context for finding new problems. The procedure should allow iterative problem context exploration through extensive literature reading, critically examining key insights, and defining tasks (Abdulla, Cramond, & Runco, 2018). In comparison, SSI-based instruction is a research-based, interdisciplinary approach that enlists higher-order problem-solving, argumentation, and research skills to analyze challenging, contextualized scientific concepts and issues (Sadler, Barab, & Scott, 2007). Personable connection to an issue is vital for initiating problem-finding. Studies suggest that the nature of the problem-situation context should enable students to express intrinsic motivation through personal experiences in argument construction (Runco, 1994). In comparison, SSI-based instruction can fulfil these requirements as its core element is a relevant and meaningful context that can probe students' moral/ethical grounds on debatable issues while leading them to become tolerant and open to differing views (Sadler, Barab, & Scott, 2007). Problem-finding studies highlighted the necessity of collaboration for a continuous and thorough discussion of a context. A collaborative informal argumentation activity allows for prolonged incubation of ideas. In comparison, SSI-based instruction provides a conduit for scientific argumentation and discourse skills that mimic how scientists research, discuss, debate, and deliberate scientific issues (Driver, Newton, & Osborne, 2000).

The literature overlap suggests that an SSI-based learning activity can function as a learning activity for problem-finding. While the research emphasizes the features highlighted above, there is a lack of operational details of the kind of inquiry, scaffolds, and implementation strategies. Thus, identifying skills and strategies required for engaging in a problem-finding activity based on the SSI model is needed. In review summary, we propose that collaborative SSI activity involving argumentation provides the conditions to facilitate problem-finding.

Purpose of study and methods

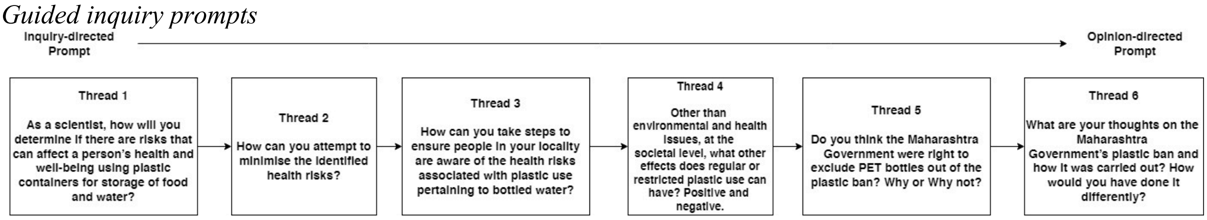
A way to illustrate the processes in authentic settings is to conduct expert modeling (Herrington & Oliver, 2000). Notably, experts with subject-matter expertise, analytical research skills, and the ability to solve ill-structured problems using interdisciplinary perspectives can highlight procedural practices. Inferences from such modeling can help identify productive reasoning strategies that assist an expert. We used case study methodology for this empirical investigation because it allows inquiry into a phenomenon within its real-life context, mainly when the contextual conditions influencing the aspect are not distinct (Strauss & Corbin, 1998). Previous studies have used SSI as a context for engaging learners to generate complex arguments (Driver, Newton, & Osborne, 2000). Also, case studies on socio-scientific argumentation have emphasized the use of moral, ethical values, and personal identity to apply scientific knowledge (Evagorou & Osborne, 2013).

The participants of the study are three Indian doctoral researchers from the fields of biology (E1), physics (E2), and mathematics (E3) based in Canada, the USA, and the UK, respectively. They were familiar with each other's research work and aptitudes. They are considered to be domain experts because of their subject-matter expertise, interdisciplinary research methodology skills, and ability to solve ill-structured problems. A group of three is considered optimal to keep a continuous interactive dialogue and avoid the discussion turning into a monologue.

The expert discussion involved the experts negotiating a controversial issue of 'Plastic-ban in Mumbai, India' through a collaborative argumentation activity. SSI-based instruction framework informed the study design (Sadler, Foulk, & Friedrichsen, 2017). The first author of the article moderated the expert discussion. The moderation objectives were to facilitate the activity at multiple levels, such as introduction through an initiation story about the SSI, setting up a web environment on Twitter, implementing a guided inquiry process for argumentation, providing guidelines, and coordinating the activity. The discussion took approximately seven hours to complete over two days. Since the participating experts were Indians, a recent major news event in the country was taken for negotiation. In 2018, the Maharashtra state government banned single-use plastic items' manufacture, use, sale, distribution, and storage. Twitter is chosen as the online discussion platform for the study. The rationale for selecting it is the social network's various affordances, such as its familiarity, its repository of diverse public opinions, the threaded conversation feature, and the 280-character limit for a Tweet. Shaw, Walker, and Kafai (2019) showed that Twitter could be a viable collaborative argumentation platform for discussing such issues.

The introductory story focused on the health problems caused by leached plastic chemicals into the water stored in polyethene terephthalate (PET) bottles. The PET bottles were left out of the plastic ban, and this situation posed a suitable discussion point for determining whether this decision was correct or not. Guided-inquiry-based collaborative argumentation was chosen to allow navigation of the complex aspects of the SSI in a transitory and collected workflow (Nam & Chen, 2017). The activity comprised six inter-dependent discussion threads with a core driving question (Figure 1). The discussion prompts are on an inquiry-to-open-ended continuum. The objective is that inquiry questions would assist in gaining familiarity with the issue by engaging in investigative practices. Whereas, open-ended questions would assist in deriving broader opinions and function as a culmination point.

Figure 1
Guided inquiry prompts



Data collection and analysis

Our primary data source is the experts' Tweets for each threaded discussion. The analysis involved using the Constant Comparative Method and Thematic Analysis (Strauss & Corbin, 1998). Each thread is considered as a case. Within a thread, an experts' Tweets are parsed into individual sentences as the unit of analysis. Compound sentences are broken down into simple sentences based on their clause.

We followed a three-step assessment level to develop the analytical framework:

1. Assessing the collaborative argumentation (Coding scheme 1)

The initial codes are developed by identifying how experts construct arguments, pose new ideas, and express their critiquing remarks. The scheme is built by open coding (Strauss & Corbin, 1998) and informed by studies on argumentation within SSI (Shaw, Walker, & Kafai, 2019). Emergent codes are added to the scheme depending on their role in the argumentation. The codes are described in Table 1.

2. Assessing the socio-scientific reasoning competencies (Coding scheme 2)

Each analysis unit is analyzed to identify themes representing the four socio-scientific reasoning competencies of complexity, perspective-taking, inquiry, and scepticism (Sadler, Barab, & Scott, 2007). The themes are described in Table 2.

3. Characterizing the meaningful problems

The third step of the analysis involved identifying the ill-structured problems found within a case. The goal is to locate episodes where the experts discovered or posed problems with social, political, economic, or scientific elements. The desired characteristics of such problems are that they should have unclear goals, insufficient information, involve multiple stakeholders, and allow various solutions. Hence, showcasing their potential for further meaningful inquiry.

Coding scheme 1 is used to identify the collaborative argumentation actions the experts engaged in for producing and exchanging reasons. Whereas coding scheme 2 is used to conceptually map the actions to socio-scientific reasoning competencies to their argumentation moves. The coding schemes help articulate the operational and reasoning processes in tandem. The experts were not explicitly told to find problems but are inferred by us. For the entire process, the first author served as the primary analyst for the data. The validity and reliability of the coding and the qualitative interpretation was mediated by regular peer debriefing with the second author throughout the analysis process.

Table 1
Collaborative argumentation coding scheme

Codes	Definition	Example
Clarify	Give an explanation about a situation or example to clarify the individual's idea.	*'I guess we could use statistics in a way that makes it more presentable and appealing…Like 9 in 10 people who use PET bottles have reduced lifespan etc.'*
Support	Any response used by an individual to accept or agree with someone else's ideas.	*'Also, as he said, PETs give an excellent option for safe and swift transportation compared to alternatives like glass.'*
Question Posing	Any response used by an individual to critique others' ideas or arguments. Response asking for further elaboration.	*'So how will you reliably get your results? (Results meaning effect on health)'*
Recognize	Acknowledge and realize the existence of factors and variables that could affect the current situation or problem.	*'however, with time plastics have changes. So, what was available 15 years ago is not the same thing you have now.'*
Propose	Give a new idea, assumption, drawing inference from information, synthesize ideas, or explanation to solve a given situational problem.	*'Experiments in-vitro can be started with different human cell-lines to determine the cytotoxicity of plastics along with effects of "food" stored in plastics.'*
Defend	Any response used by an individual to persuade others about his/her ideas; responses for expressing confidence in one's ideas.	*'I would say that most items sold in PET bottles aren't essential for life and survival (correct me if I am wrong).'*
Reject	Any response used by an individual to disagree with all or part of a peer's ideas.	*'To just rebut that, in all honesty, I don't think the lower economic strata of society are affected by these price changes.'*
Evidence	Use of scientific data, information sources, personal anecdotes, prior general knowledge to support their argument.	*'These are immortalized cells that have been harvested multiple years ago, which the scientific community can use.'*
Casual Talk	Any casual response used by an individual to address a peer's comment such as exchanging words of praise, off-topic conversations.	*'Hear me out here.' 'Well said.'*

Table 2
SSR based argumentation characteristics coding scheme

Code	Theme	Representative Quote	Mapping to SSR competencies
Making Connections	Consider issue's inherent characteristics and handling	*'For the experiment... I guess people in rural areas*	Recognizing the inherent complexity of SSI.

	multiple pieces of information by connecting to elements within the issue.	*(usually) do not use plastic containers for food or water storage.'*	
Agreement Stance	Participants stating their agreement, disagreement, or a neutral stance.	*'I agree with your premise.'*	Examining issues from multiple perspectives.
Adding Information	New Information selection from an external source or prior knowledge.	*'Here's the problem with PET containers: Polyester Isophthalic acid (IPA) and terephthalic acid (TPA) are the main carboxylic acids used in polyester coatings'*	Adding Information
Synthesis Questioning	Questions directed to construct a new idea linked to a specified theme.	*'So how will you reliably get your results? (Results meaning effect on health)'*	Appreciating that SSI are subject to ongoing inquiry
Evaluative Questioning	Critique others' ideas or arguments by posing a question. Question asked to elaborate	*'Why don't we use this to reduce health issues?'*	Appreciating that SSI are subject to ongoing inquiry
Inference Construction	Compiling, sorting key agreed	*'Statistics, visual aid, advertisements, mandatory regulations, all would be imperative to ensure any research seeing daylight!'*	Appreciating that SSI are subject to ongoing inquiry
Analyzing Presented Argument	Critically examining claims, evidence, and	*'I doubt scientific data in its raw form would help the cause.'*	Appreciating that SSI are subject to ongoing inquiry

Findings

Experts engaged in a range of conversation types (discourse, debate, dialogue) and shared a varied number of Tweets across the threads We applied the analytical framework to sequentially code the Twitter threads with coding schemes 1 and 2. For concise explanation, strategy 1 is illustrated in Figure 2 how the codes led to its formulation. A sequence of grid units with the same colour represents a Tweet or a series of Tweets added by an expert. Each grid unit in Figure 2 is a unit of analysis. Each unit contains an argumentation code (regular type) and an SSR code (italicised type) for a unit of analysis. This process is repeated for each such instance within the six threads. We then located the argumentation segments that led to a problem. These are analyzed in detail in their respective context (called Strategy Scenario).

Strategy 1: Provide alternative reasoning for a phenomenon

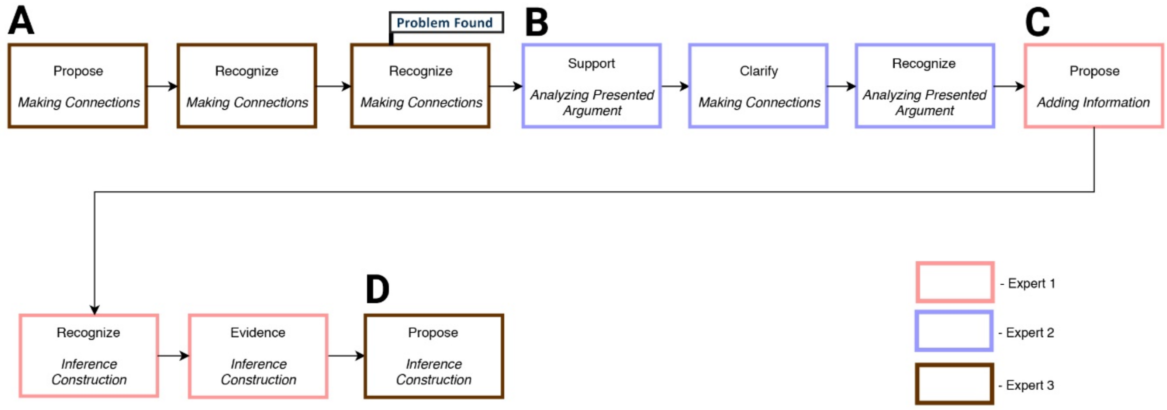
Strategy scenario: Expert 3 mentioned that although the popular opinion for the exclusion of PET plastic from the ban was due to their heavy use, it could be that lobbying by plastic companies could have influenced the decision taken by the government ('A' segment in Figure 2). E1 and E2 substantiate further by supporting it ('B' & 'C' segment in Figure 2). Problem found: Corporations could have influenced the plastic ban through lobbying. Analysis: A participant provides an alternate reason as the causality for a situation or phenomenon. The SSR competency for exhibiting scepticism is seen in this case. The participant critically examines a commonly accepted reason for a situation.

Strategy 2: Identification of a missing variable or missing information

Strategy scenario: Expert 1 proposed an experimental design to determine the health risks of plastic use for storing food and water. E1 outlined that instead of direct human trials, in-vitro experiments perusing different human cell lines can be conducted to determine the cytotoxicity of plastics. E1 mentioned the advantage of the experiment design by stating that a large sample set of humans exposed to consuming food stored in plastics can assist in conducting surveys and collecting samples. E2 agreed with the argument but highlighted that plastics have changed over time (missing variable), and hence, their effects on human health would be variable as well. E2 raised doubt over the reliability of the proposed experiment and posed a question to E1 for further explanation.
Problem found: Over time-varying plastic types have had different effects on human health. Analysis: A structured argument provided by a participant is agreed upon by a peer The peer then points a missing variable, which affects

the initial argument. Peer then poses a question asking for further explanation. The construction of the initial argument involves backing the core idea by adding relevant information (inquiry), identifying variables affecting the situation (complexity), complemented by analyzing its pros/cons (scepticism), and synthesizing an inference (inquiry).

Figure 2
Strategy 1 identification



Strategy 3: Abstracting inferences from externally sourced new information
Strategy scenario: During the co-construction of an argument, E2 highlighted the requirement to focus on studies on the stability of PET plastic under different conditions. E1 referred to an external information source and posted a relevant excerpt. The information blurb stated that polyester resins are unstable in acidic conditions. E1 extracted an inference that although PET plastic has poor corrosion resistance, it is still used to store acidic colas and soda. Problem found: Acidic beverages like colas are stored in plastic bottles, with poor corrosion resistance. Analysis: A requirement for external information is recognized. A participant refers to a source and extracts a relevant piece of information. The information is added to the conversation flow. The participant synthesizes an inference (the inference may not apply to ongoing discussion) by making connections to other phenomena related to the new information. Inquiry abilities to identify a valid information source and extract the relevant parts are crucial in this scenario.

Strategy 4: Identifying probable use of a constructed argument in another situation
Strategy scenario: The experts co-constructed a coherent experiment design to quantify the health hazards of plastic use for storing food and water. E1 mentioned that the designed experiment could address another problem. Specifically, people reuse PET bottles even though the instructions suggest crushing them after using them. Their experiment could help in determining the corroded plastic, which would be ingested in future reuse of plastic bottles. Problem found: Instructions for PET plastic use are not followed (crush after use), which can lead to corroded plastic ingestion. However, future ingested plastic can be quantifiably determined. Analysis: This strategy is like Strategy 1 in how a peer agrees upon a structured argumentation. In this case, the difference is that the peer recognizes that the argument has a real-life application for addressing another problem. The reasoning elements in play here are perspective-taking and accounting for another attribute in the SSI (complexity).

Strategy 5: Taking a perspective or point-of-view stance for argument construction
Strategy scenario: E2 explained that people in lower economic strata could not afford expensive alternatives like glassware and relied on PET plastic. E1 rejected this argument and stated that people at lower economic levels are not affected by the price changes as their exposure to PET is from the reuse of bottles that have been scavenged. Problem found: A plastic ban can affect people differently depending on their economic background. Analysis: A peer rejects a participant's idea. The peer constructs a sound argument in the rebuttal that involves an initial opinion backed by relevant evidence. The participants agree with the reasoning presented in the rebuttal. A problem is identified within the rebuttal argument. The competencies interplaying in this strategy is perspective-directed argument construction complemented by inquiry practices for justifying the reasoning. The element of scepticism is also observed as the participant critically examines a posed argument.

Strategy 6: Dividing an argument into its fundamental elements
Strategy scenario: The core idea of 'plastic ban' is abstracted to a generalized 'ban' and 'plastic' concepts. E2 mentioned an anecdote that an alcohol ban in the USA led to hoarding, and it could be possible that the plastic ban could lead to modern-day hoarding of plastic. Also, E2 mentioned that plastic clogged the stormwater drains

in Mumbai, which worsened the flooding. Problems found: A plastic ban could lead to hoarding of plastic like other restricted substances like alcohol. Plastics exacerbate flooding by clogging storm drains. Analysis: This strategy involves a participant recognizing a problem that had occurred in another issue or situation. The connection suggests that a similar problem could also occur in the current topic being discussed. This strategy is dependent on understanding the complexity of the issue to identify the various fundamental elements in it. It involves inquiry-directed argument construction wherein the participant retrieves information from another context where the concerning aspect was also affected.

Discussion

The case study exploration showed that the designed SSI-based activity fulfilled the conditions required for facilitating problem-finding. The study explored the processes necessary for engaging in a problem-finding activity situated within an SSI. The interactions showcased by the domain experts reflected the strategic use of collaborative argumentation and socio-scientific reasoning competencies. Our findings align with the variables influencing problem-finding performance (Abdulla et al., 2018; Lee & Cho, 2007).

Strategies 1 and 2 featured science process skills such as inferring, evaluating, and controlling variables; in applying scientific knowledge for constructing well-informed arguments. The arguments, in turn, served as reasoning 'seeds' for finding problems within the SSI. The findings corresponded to previous studies, which have pointed out that scientific knowledge (Lee & Cho, 2007) and science process skills are predictors for problem-finding (Bernardo, 2001). As an application, these can also be introduced as a PF phase within teachers' collaborative action research process to design SSI curricula (Lee and Yang, 2019).

Runco and Acar (2010) showed a positive relationship between divergent thinking and problem-finding. In a different setting, Lee & Cho (2007) presented that divergent thinking positively affected problem-finding in a moderately structured problem, negatively in an ill-structured problem context. The results from this study can be extended as operational steps for implementing divergent thinking skills. This can be done by expanding thinking space by parsing a phenomenon into its fundamental elements for finding new ideas (Strategy 6). Also, the deliberate search for potential applications of a co-constructed argument (Strategy 4) and identification of other reasons for a phenomenon (Strategy 3) could function as triggers to initiate problem-finding.

Strategy 5 involved critically examining a posed argument from a perspective opinion that refutes it. The rebuttal is constructed by providing appropriate reasoning and evidence. In this situation, a view is transformed into a reasoned argument backed by evidence leading to a new agreement stance among the stakeholders. The problem is identified within the differing explanations for a particular situation. This finding refers to the core issue's ill-structured nature, which allowed for posing a perspective-based idea. It highlights the expression of strong motivation by a participant for constructing a persuasive rebuttal argument. Also, the findings support Shaw, Walker, and Kafai (2019) 's findings that Twitter can be used for complex socio-scientific argumentation.

We inferred additional conditions which appeared vital for maintaining the smooth flow of argumentation. Notably, using an immediate controversial issue as a context allowed sharing personal social anecdotes and cultural experiences for argument construction. We speculate that the friendship shared by the experts (who had known each other for the past eight years) powered the free exchange of diverse ideas, personal experiences, and radical opinions without any fear of judgment. The rapport within the argumentation corroborates that personal narratives are essential for teaching controversial SSI (Levinson, 2008). Their subject-matter expertise proved vital in resolving conceptual differences and dissenting opinions by providing reasoned arguments with empirical evidence.

The problems and conclusions drawn in the discussion are accepted as tentative, and the need for continuous investigation for enhancing scientific knowledge is recognized. Also, the activity is held within an informal space, with the experts having no obligations connected to it. Twitter is mainly for linear conversations, making referring and responding to earlier posts difficult. The plastic ban issue was ephemeral and localized. It had multiple opportunities for sharing personal stories, which might not be possible in other issues. Another limitation is that the research design is entirely based on three STEM domain experts' interactions. We believe that insights from a social sciences expert could have substantiated the collaborative negotiation. The strategies discussed in this article are non-exhaustive, and other categories could emerge in varied learning settings. Future work can focus on addressing these limitations.

Our results can be employed in devising practical, productive strategies for implementing a structured and deliberate activity for finding researchable problems, specifically for novice learners in similar situations (Belland, Kim, & Hannafin, 2013). This would require integrating the collaborative argumentation and socio-scientific reasoning practices with the procedural steps reflected in the strategies identified by us. Thus, it could be a foundational step for inquiry or project-based learning. Studies with novices will need to be conducted before any implementation efforts. Also, results suggest that problem-finding is not solely a theoretical or speculative activity. For instance, the predictions made by the experts (in October 2018) that the plastic ban in Mumbai would fail and that corporations could influence/lobby for the ban had occurred (Bhushan, 2019).

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