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Exploring Student Problem Finding to Promote Science Learning in the Classroom

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Abstract

While many studies have been conducted on problem solving and its application in science classroom contexts, comparatively little is understood about the process and efficacy of student problem finding as well as its implications for classroom learning. This paper presents findings from a recent pilot study on student problem finding among mixed ability students learning science in a Singapore primary school. As part of a larger research study designed to generate empirical support for preparatory benefits of problem finding and to better understand the basic design of an efficacious problem finding based lesson, this initial study sought to address two related fundamental questions: 1) Can students generate problems relevant to target science concepts they have yet been formally taught? 2) What kind of problem finding task can help students generate problems relevant to target science concepts?

Findings suggest that a problem finding task design which integrated relevant data into the problem situation descriptive text yielded more consistent problem finding performance than text only design. Yet, students on the text only task attained higher mean score for transfer item in the immediate posttest than those who worked on tasks with additional supporting data. In the long run, these problem finding investigations are likely to generate interesting lines of inquiry into the use of problem finding to not only help students learn science better, but also develop their dispositions of inventive thinking and creativity.

Keywords: problem finding, preparatory learning, conceptual understanding, transfer, science education

Exploring Student Problem Finding to Promote Science Learning in the Classroom

Introduction

Recognition on the significance of problem finding in advancing and deepening our understanding and capacity to navigate our world has been articulated by eminent scholars and scientists, including Einstein and Infeld (1938) who presented an insightful, thought provoking comparison between the nature of problem finding and solving. Reflecting on Galileo's attempt to experimentally determine the velocity of light in their classic book *The Evolution of Physics*, they wrote that "the formulation of a problem is often more essential than its solution, which may be merely a matter of mathematical or experimental skill. To raise new questions, new possibilities, to regard old problems from a new angle, require creative imagination and marks real advance in science." (p. 95). Past studies and reviews on educational research have also produced considerable empirical evidence that support claims on relationships between problem finding and better problem solving (e.g. Silver, 1994), creativity development (e.g. Jay & Perkins, 1997), conceptual learning (e.g. Chin & Chia, 2004). In fact, a survey of literature in mathematics problem posing reveals both research interest and gaps that can lend strong justification for further investigation into problem finding to promote student learning.

Studies on the influence of problem posing on student learning mathematics have recognized the value and multi-faceted role of problem posing in helping students learn mathematics. Surveyed literature on mathematical problem posing included reviews (Jay & Perkins, 1997; Kirkpatrick, 1987) and individual studies (e.g., Silver & Cai, 1996) that presented theoretical and empirical evidence supporting the case for problem posing as an instructional strategy (Winograd, 1991) and learning goal in itself (English, 1997, 1998). Other studies examined factors that influence problem posing performance (English, 1997;

Silver & Cai, 1996) and attempted to shed light on the underlying process (e.g., Ramirez, 2006). What emerged from this quick survey was the observation that there appeared to be insufficient experimental and quasi-experimental studies on the influence of problem posing instructional strategy on learning new mathematical concepts. More significantly, no studies have been found that compared the efficacy of problem posing instructional strategy with other instructional approaches. This is evident in a recent edition of *Education Studies in Mathematics* (2013, May) that focused on the issue of “Problem Posing in Mathematics Teaching and Learning”. Out of 15 articles, there was only one descriptive study (Ticha & Hospesova, 2013) that looked at incorporating problem posing as part of training pre-service primary school teachers.

As such, there is an impetus for research into the process and effects of problem finding to better understand how teachers may engage and develop students’ problem finding skills and dispositions. The main rationale is to help them learn the academic subjects better in the classroom. In the long run, it should also better equip students to face and surmount existing as well as emerging challenges of the 21st century.

A comparative examination on some major 21st century competencies frameworks advocated by various educational institutions (Dede, 2010) arguably showed much effort been justifiably devoted towards developing students’ problem solving skills and ability. However, the lack of consideration on developing problem finding skills was also evident. In spite of the relatively small but growing body of research that recognized the contribution of problem finding to endeavors in educational, scientific, artistic, management fields, it apparently has not attracted as much attention in comparison with the abundance of research and applications on problem solving (Jay & Perkins, 1997). Hence, it is hardly surprising that our current understanding on problem finding is rudimentary. From the educational research perspective, we do not know enough to explicate the learning pathways afforded by

problem finding and its effects on student outcomes. We have yet to establish design principles for problem finding based pedagogy that may be implemented to promote classroom learning.

Literature

How does problem finding look like?

A survey of past studies that included students generating problems as part of the investigations revealed an absence of an established term to define problem finding. This is shown by the diversity of terms various researchers have used, for example, problem *creation* (Smilansky, 1984); *construction* (Reiter-Palmon et al., 1997), *discovery* (Brugman, 1995), *detection* (Klein, Pliske, Crandall & Woods, 2005), *definition* (Getzels & Csikszentmihalyi, 1976), *formulation* (Brugman, 1995; Kirkpatrick, 1987) *identification* (Subotnik & Steiner, 1994), *posing* (Perrin, 2007; English, 1998). While it is not a focus of this paper to arbitrate which term might best represent the phenomenon or sort out the relative merits of each, it is crucial to operationalize the problem finding phenomenon and attain some clarity on its meaning within our research context. To this end, we have chosen Getzels' (1982) definition of problem finding as an act of "envisioning and creating new, deeper questions and fresh avenues for inquiry that must be posed and formulated in fruitful and often radical ways if they are to be moved toward solution" (pp. 37-38). This definition stood out amongst others in its distinctive emphasis on seeking depth through "deeper questions" and new understanding through "fresh avenues for inquiry" – two notions that arguably constitute worthwhile goals in many learning endeavors. This is also consistent with Silver's (1994) view of problem finding as a desirable event. Supporting this view in an earlier journal article, Getzel (1975) contrasted his notion of a "problem" with the more common, intuitive understanding of a problem as an occurrence that is undesirable and to be avoided or

mitigated. To us, a critical feature common to both definitions appears to be the intentional, deliberate effort to promote student problem generation to better support their learning.

Dillon's (1982) taxonomy of problem types contributed further clarity in characterizing and operationalizing problem finding. In his taxonomy, Dillon described three types of problems that may be positioned along a continuous spectrum: 1) presented problem 2) discovered problem, and 3) created problem. At one end, a problem is considered "presented" to a student when the problem situation and its salient features are known and defined by others such as the teacher. At the other end, a problem is "created" when the problem finder generates and defines the problem situation and pertinent problems where none existed. Between both ends, the problem finder "discovers" a problem constrained by a problem situation given to him and his prior knowledge on the subject matter he perceives as relevant to the given problem situation. Accordingly, our reported studies may be considered as an investigation involving students in acts of *discovering* problems, to adopt Dillon's terminology, when they were learning new science concepts. Such a view makes it clear that problem finding activities would involve the initial step of providing students with a carefully designed problem situation containing references to target science concepts, necessary contextual information and problem finding instructions. This is in contrast to cases where students themselves create the problem situation within an information rich environment and then generate investigable problems (e.g., Roth & Bowen, 1993).

Thus, in this paper, problem finding has been operationalized as an act of students generating new problems using information provided in a given problem situation to promote science classroom learning in terms of conceptual understanding and learning transfer.

What do we know about problem finding in the science classroom?

Two key observations became apparent in a survey of past studies involving students generating problems and questions in the science classrooms. The first observation was the somewhat *underrepresentation* and corresponding disproportionately smaller emphasis and investment on problem finding in the classroom when compared to problem solving. The other observation revolved around the nature of past investigations that incorporated some forms of problem finding on the students' part during lessons.

The survey of relevant literature brought to light a common concern over the lack of emphasis educators have attached to problem finding in the classroom. Both Washton (1967) and later Siu (2001) noted that problem finding was rarely taught during the process of problem solving. Similarly, Ramirez (2002) suggested that problem finding was "the most neglected aspect of skills building in education". Perkins (2009) further observed that, vis-à-vis problem solving, there were insufficient opportunities afforded by today's educational systems for students to develop problem-finding skills. Drawing on empirical evidence gathered over a four-year exploratory study on how elementary students went about finding useful problems that have never been solved, McIntosh (2011) argued for the need to look at how we can create a generation of problem finders, not merely produce better problem solvers. Indeed, these studies collectively supported the case for further research on problem finding phenomenon. Although studies investigating the nature and efficacy of problem-finding exist, they pale in comparison with the abundance of research that focused on problem solving and problem-based instructional methods (Jay & Perkins, 1997). Consequently, we know a lot more about problem solving and how to develop students' problem solving ability than problem finding.

Our attempt at organizing the collection of past studies related to problem finding surfaced in our literature search revealed a seemingly disorganized body of past research. While some studies did make reference to others, there appeared no evidence of research

themes or clear lines of inquiry that thread these studies in some meaningful, coherent manner. To date, only one review (Jay & Perkins, 1997) may be clearly seen as a clear attempt to propose an organizing framework for studies conducted. Their framework categorized those studies under four themes: context, cognitive abilities, cognitive processes and dispositions. Guided by the overarching goal of understanding the underlying motivation and cognitive mechanisms for problem finding, the authors argued that the context in which problem finding occurs and problem finders' domain knowledge were two factors that enabled or inhibited problem finding. Dispositions for problem finding, for example the willingness to extensively explore a novel situation, and mental strategies might help account for the problem finding process. While their review may arguably be seen to bring some coherence into the seemingly disorganized body of past research and useful in illuminating the problem finding process and factors that influence the process, it did not appear to include studies examining the effects of problem finding on outcomes of students learning science. In addition, our survey also raised the likelihood of another deficit in problem finding research: we do not know whether and to what extent student learning may be affected by carrying out problem finding within different lesson designs. In other words, the "problem" of pedagogical significance appears to be a deficit in our current understanding on how problem finding, as an instructional intervention, may be implemented within the constraints of classroom practice and conditions to extract its efficacy in promoting optimal learning. The existence of this gap, if verified, has significant implications on understanding and designing for problem finding to promote learning in the classroom.

To verify this gap, we focused on science classroom based studies identified in an extensive search of educational databases (e.g., Education Research Complete) and peer-reviewed journals (e.g., Journal of Research in Science Teaching). The search was delimited to empirical studies involving students carrying out problem finding related activities, such as

generating questions on predetermined topics (e.g., Chin, Brown & Bruce, 2002; Ergun, 2010). To facilitate our analysis, we organized these studies into two main groups. The rest of this section provides an outline of key findings from both groups of study.

Group I Studies: Factors that affect problem finding process and performance

The review of Group I studies raised four insights that were informative in understanding the influence of personal and environmental factors on problem finding. First, different researchers generally agreed that there were no gender differences in problem finding performance (Hoover & Feldhusen, 1990; Franske, 2009; Hu et al., 2010). Increasing age (grade level) also appeared to predict correspondingly better performance measured in terms of problem variety and originality (Hoover & Feldhusen, 1990; Hoover, 1994; Chen, Zhang & Cai, 2006) although contrary findings were also found (Hu et al., 2010). Similar to influences of age (grade level), academic ability also seemed to influence problem finding outcomes (Dori & Herscovitz, 1999). Prior knowledge on a topic that students found problems on and the relevance of information provided in the problem situation generally correlated positively with problem finding performance (Hoover & Feldhusen, 1990; Hoover, 1994; Mestre, 2002; Savelsbergh, de-Jong & Ferguson-Hessler, 2002; Molinero & Garcia-Madruga, 2011). However, the studies painted a picture of an inconsistent relationship between relevance of given information, problem quantity and quality. For example, Molinero & Garcia-Madruga (2011) found that increase in amount of relevant information led to significant increase in number of questions generated but no significant difference in quality of questions posed. Finally, lesson designs that included scaffolds during problem finding strengthened students' ability to formulate useful problems (Zydney, 2005; Yu, Tsai & Wu, 2013). Zydney (2005) reported in his quasi-experiment involving 8th grade students that among three types of scaffolding afforded by a multimedia software learning

environment, namely organization, higher-order thinking and a combination of both, the organization scaffold was found to have the greatest effect on the quality of student generated questions. Yu, Tasi & Wu (2013) examined the effect of delaying or withholding scaffolds. They reported that their 5th grade students with access to scaffolding throughout a question generation based intervention performed better than those with partial and no access to scaffolds. While these studies collectively add to our understanding on factors that promote or inhibit student problem finding performance, they were unable to show how problem finding based instructional designs compared with those that did not employ problem finding. They were also weak in revealing the extent problem finding, when nested within other learning activities, had contributed to reported student performances (e.g., Keys, 1998).

Group II Studies: Effect of problem finding on student outcomes

While these studies generally argue favorably for the efficacy of problem finding in student learning, there are two noteworthy observations instrumental in helping to shape the study reported here. One pertains to the difficulty in determining the extent problem finding has contributed to student learning outcomes. This situation emerged largely as a result of the research study designs in which problem finding was one of the activities students engaged in during learning (Roth & Bowen, 1993; Kay, 1994; Sadeh & Zion, 2009; Ergun, 2010; Molinerio & Garcia-Madruga, 2011). In other words, problem finding was not foregrounded but nested within other lesson activities. It becomes challenging to arrive at more certain conclusions about the nature and extent of its effect on student learning.

The other observation is that many of the reviewed studies were premised on the assumption that students already possessed some relevant topical knowledge received during or from previous formal instruction prior to engagement in problem finding. They were first provided with or had access to relevant information (Kay, 1994; Chin & Chia, 2004; Rens, Pilot & Schee, 2010; Molinero & Garcia-Madruga, 2011) or were taught the theoretical

concepts (Ergun, 2010). This is consistent with Jay & Perkins' (1997) review on problem finding research involving expertise and conceptual change that suggested prior knowledge was a necessary but insufficient condition to enable problem finding. This view also agrees with an earlier study on effects of prior knowledge on students' ability to understand counterintuitive science text (Alvermann & Hague, 1989). Their study demonstrated that activating students' prior knowledge on Physics projectile motion helped them comprehend the given text better provided they were made aware that the textual information might conflict with their naïve conceptions. To date, however, we found no study that investigated whether students can problem find if they did not possess prior knowledge or have not been taught the targeted concepts. Is it even possible to generate meaningful questions when one does not know, in a formal sense, about the topic? This line of inquiry created a theoretical conundrum that, when addressed, could potentially make a significant contribution to our understanding on how people find and solve problems.

To summarize, the review of relevant literature brought to fore the need to explore in-depth problem finding as an instructional strategy to help students learn new concepts. Premised on extensive studies in Productive Failure that provided substantial empirical evidence on effectiveness of solving novel problems *before* receiving formal instruction on new mathematics concepts (Kapur, 2008, 2012), this investigation into problem finding, in which the pilot study reported here constituted the first step, would take shape in two key phases: The first phase focuses on building an empirical basis for problem finding in student learning and working out the basic design of an efficacious problem finding intervention. The subsequent phase primarily compares the efficacy of pre-instructional problem finding with other instructional designs where students generate problems during or after formal instruction. Extending further, comparison may also be made between problem finding and cognitive conflict, an instructional strategy seen as one of the most common approach to

promote common conceptual change (Limon, 2001). In doing so, we may better understand the relative merits of both strategies in activating and differentiating students' prior knowledge, and also help them develop greater awareness on implicit representations they hold about phenomena in the physical world (Vosniadou et al., 2001).

Framed within the larger research direction and context, this pilot sought to address two basic issues. Past studies revealed that a lack of a standardized instrument to trigger problem finding and obtain student responses. Problem finding tasks were customized to the research context, subjects and goals of respective studies. Here, one issue that needed to be adequately resolved was how the problem finding task might be designed and used in the classroom for optimal problem finding performance in terms of problem quantity and quality. In addition, it was unclear how these students might respond when tasked to find problems related to a concept they have yet been formally taught. What kinds of problems would they generate? Would problem finding performance be significantly hindered or perhaps even prevented by the lack of sufficient scientifically normative knowledge?

Purpose

In this paper, we report a pilot study on problem finding in the context of primary science classroom learning. This initial study is part of a doctoral research study that focuses on examining the process and outcomes of problem-finding as well as establishing a basic design of an efficacious problem finding based pedagogy. Specifically, we sought to address two related questions:

1. Can students generate problems relevant to target science concepts they have yet been formally instructed?
2. What kind of problem finding task can help students generate problems relevant to target science concepts?

The study was carried out in two parts during curriculum hours to test three problem finding task designs and determine the design that would yield optimal problem finding performance. Through this process, we wanted to develop a suitable instrument to trigger problem finding behavior among students on a science concept which they have not been formally taught in class. The target concepts were specified in the national curriculum for primary science (Ministry of Education, Singapore, 2008).

Methodology & Results

Pilot Study (Part One)

Participants

Participants were 30, Primary Four (4th grade) science students from two classes in a mainstream, co-educational public school in Singapore. Students were almost of Chinese (50%) and Malay (33%) ethnicities. Parental consent was obtained for these students to participate in the study. All 30 students took part in both parts of this pilot study conducted two months apart.

Research Design and Procedure

A quasi-experimental design was adopted to collect and analyze students' responses to two structurally different researcher developed problem finding tasks involving the concept of heat transfer in different solid materials. Prior to working on the problem finding task, the students had been taught in school that heat is a form of energy which travels from a region of higher temperature to one that is lower. However, they had not formally encounter the idea of heat traveling at various rates across different materials.

Situated in their regular classrooms, students individually generated problems in the form of questions within 20 minutes using information presented in the problem finding

task. The 30 students were randomly assigned to complete either task. All of them also took a 4-item written survey after completing the problem finding activity to collect their feedback on the problem finding activity they had just completed. Due to constraints in the school timetabling, these students completed both task and survey in two separate groups within the same morning. The first author facilitated the problem finding activity for both groups.

Data Sources and Analysis

Problem finding tasks

Two structurally different problem finding tasks involving the same problem situation were developed for this investigation:

Task 1 (Text with tabulated data): Students were presented with a narrative describing a problem situation with supporting data in the form of a table of temperature readings taken for handles (wood & stainless steel) of two otherwise identical cooking pots (Appendix 1).

Task 2 (Text only): The problem situation was presented in a narrative with no supporting data (Appendix 2).

To determine the problem finding performance of both groups, the student generated questions were analyzed using an analytical scheme developed for this study. First, questions generated by each student were grouped according to question stems (e.g., what, why, how). Next, questions in each question stem group were further classified according to critical features that could be related to ideas on heat transfer, heat in general as well as the problem situation described in the task. The mean number of different questions and question categories generated by students working on each problem finding task were taken to be a measure of knowledge activation and differentiation.

An added level of analysis was carried out to determine the number of “higher quality” questions, that is, comprehensible questions that clearly directed students towards the idea of differential heat transfer. For example, an actual student question “If we cook on fire, which handle will be hot?” will be considered a “higher quality” question compared against another actual question “Why does water vapor come out of the pot?” This finer grain analysis may be useful in helping to determine the extent which a particular problem finding task design might activate the desired prior knowledge associated with the target concept.

Engagement & mental effort

After completing the problem finding task, students individually took a four-item, seven-point Likert scale survey. These items collected data on students’ perception of task difficulty, interest in task, mental effort exerted and extent in which they would like to attempt similar problem finding tasks in the future.

Results

Problem finding tasks

Students (N=15) who worked on a problem situation presented in words with no supporting numerical data (Text only group) performed better than students (N=15) who had additional supporting data to work with (Text with data group). The text only group generated on average about nine questions (M=8.6, SD=3.31) compared to an average of about six questions by the text with data group (M=5.7, SD=2.35). Discounting student generated questions that were ambiguous, unclear or unrelated to the target concept, the text only group generated on average about seven questions (M=6.5, SD= 1.92) compared to the text with data group (M=3.7, SD=1.80). The text only group also performed consistently better in terms of the number of “higher quality” questions i.e. comprehensible, relevant questions that pointed students more directly towards learning the target concept. The text

only group generated on average about five “higher quality” questions ($M=4.53$, $SD= 2.26$) whereas the text with data group managed about two ($M=2.2$, $SD=1.57$) (See Appendix 3 for a sample of “higher quality” questions compared with other relevant student questions). However, both groups yielded an almost similar weighted question quality score: Text only ($M=1.72$, $SD =0.28$); Text with data ($M=1.66$, $SD=0.39$). The weighted question quality score was each group’s mean number of relevant question (only questions related to target concept) generated with double weightage assigned to each “higher quality” question.

Engagement and mental effort survey

Each item in this four-item survey used a seven-point Likert scale adapted from a more comprehensive survey tested in earlier preliminary studies involving mathematical problem posing. Students in the text only condition found the task easier and slightly more interesting. They also reported a more positive perception on the problem finding activity in terms of likelihood in attempting future similar activities ($M=5.5$, $SD=1.25$) than the text with data group ($M=4.4$, $SD=1.92$). On the other hand, the text with data group reported a lower mental effort spent working on the activity ($M=4.2$, $SD=1.42$) than the text only group ($M=5.1$, $SD=1.41$).

Conclusion (Part 1)

The findings shows that a problem finding task in which the problem situation was presented in text-only narrative appeared to promote problem finding more strongly than one that included additional relevant data presented within a table. This is consistent with findings in past studies that showed students working with less structured problem finding tasks generated a larger diversity of problems than those with more structured tasks (Lee & Cho, 2007). Further examination, however, raised two pertinent questions:

1. Can the manner in which additional supporting data is given influence students' problem finding performance?
2. Is there a discernible difference in terms of learning outcomes between students engaged in two different problem finding tasks?

Pilot Study (Part Two)

A follow-up investigation was carried out to address two new questions raised in the preceding investigation. Using concepts from another topic (global warming) specified in the science curriculum, this round of investigation differed from the first on two levels:

1. A new task design – additional data relevant to the problem situation integrated into the text-only narrative – was tested;
2. Teacher instruction on target concepts was carried out after the student problem generation phase.

Participants

In order to compare findings from both parts of the pilot study, the same 30 Primary Four students were involved. The first author facilitated the problem generation activity and taught the target concepts in their regular classrooms. Students and their science teachers also verbally confirmed that the target concepts have not been formally taught in class.

Research design and procedure

A quasi-experimental, posttest only design was adopted for this investigation. It was carried out according to the same procedure as the earlier investigation with the exception of the instructional phase subsequent to student problem generation. To address the question on effect of the manner in which additional relevant data was provided to students, a new

problem finding task based on a recent, local news report on unusually heavy rain – a weather phenomenon commonly linked to global warming – was developed. This new task utilized text with integrated data design whereas the other task retained the text only design found to yield better student performance in the earlier investigation. Students were again randomly assigned to complete either task.

Data sources and analyses

Problem finding tasks

Task 1 (Text with integrated data): Students were presented with a problem situation with supporting data integrated into a short narrative describing local weather details (Appendix 4).

Task 2 (Text only): The problem situation was presented in a short narrative with no supporting data (Appendix 5). This task was structurally similar to Task 2 used in the earlier part of the study.

Posttest

A 5-item researcher-developed posttest was developed to gauge the effect of problem finding task design on subsequent instruction. Students individually took the posttest after the teacher instruction. Performance in this posttest served as a measure of learning in terms of a) factual recall (2 multiple-choice items on identifying main greenhouse gas and activity that generates largest amount of greenhouse gases; 1 open response item on describing two global warming effects), b) conceptual understanding (1 open response item on explaining the relation between greenhouse gases quantity and global warming) and c) transfer (1 structured item with two parts on explaining interior temperature differences of three similar vehicles parked outdoors throughout a day). All items were equally weighted and each correct response was awarded one mark. Average posttest score for both problem finding

task groups were compared to obtain an indication on the task design that resulted in better conceptual learning outcomes.

Engagement, mental effort and topic interest survey

After completing the posttest, students individually scored on the five-item survey, similar to the four-item survey used during the earlier investigation with the exception of an additional item – likelihood of finding out more about the topic mentioned in the activity. This fifth item was included to determine whether any difference existed between students who attempted different problem find tasks on their interest to find out more about global warming.

Teacher instruction

This investigation included a 20-minute *post* problem finding teacher instruction. In this phase, students were seated in their regular classrooms and the first author – an experienced science teacher – taught the lesson. The instruction mainly comprised a presentation interjected with questioning and answering on three aspects of global warming: definition, cause and effect on humans. Students attempting both problem finding tasks received the same instruction.

Results

Problem finding tasks

Data revealed that students in the text with integrated data group (N=14) performed better than students in the text only group (N=16). The text with data group generated on average six questions (M=5.6, SD=2.14) compared to an average of about five questions by the text only group (M=4.6, SD=2.39). After discounting questions that were ambiguous, unclear or unrelated to the target concept, the text only group generated on average about four

questions ($M=4.2$, $SD=2.1$) compared to about five questions by the text with data group ($M=4.9$, $SD=1.73$). The same trend was observed in the number of “higher quality” questions, with the text with data group generating an average of about three “higher quality” questions ($M=3.4$, $SD=2.1$) and the text only group managing around two ($M=2.1$, $SD=1.48$). Interestingly, compared against the earlier investigation, both groups again yielded an almost similar weighted question quality score: Text with integrated data ($M=1.69$, $SD=0.31$); Text only ($M=1.61$, $SD=0.38$).

Posttest

The text with integrated data group performed slightly better than the text only group. Out of a maximum score of 7, the former group achieved an average final score of 2.57 ($SD=1.5$) compared to the latter ($M=2.44$, $SD=1.31$). An item-by-item analysis revealed that the text only group appeared to score better for the transfer item (Q4) while the text with integrated data group scored on average higher for recall (Q2 & 3) and conceptual understanding (Q5) items. No difference was found for the first item on recall (Q1).

Engagement, mental effort and topic interest

Students in the text with integrated data group reported more positively in all the first 4 items. On average, they found the task easier, required slightly less mental effort to complete, slightly more interesting and liked to attempt similar tasks again. For the additional fifth item measuring interest in the Science topic, the text with integrated data group showed a comparatively deeper interest in finding out more about the topic ($M=4.6$, $SD=2.02$) than the text only group ($M=3.8$, $SD=2.34$). This trend is comparable to item 4 that measured interest in the problem finding activity. For this item, the text with integrated data group appeared to register deeper interest ($M=4.1$, $SD=1.41$) compared with the text only group ($M=3.6$, $SD=1.59$).

Conclusion (Part Two)

Content analysis of student generated questions and survey results suggest that a problem finding task with additional relevant data integrated into the problem situation narrative appeared to promote problem finding more strongly than a task with no additional data given. This seemed contrary to findings in the earlier investigation where students using the task with no additional given data demonstrated better problem finding performance. In addition, posttest suggested that the text only design for problem finding might have facilitated transfer of learning but not recall and conceptual understanding. While these findings provided an initial sense on the effect of problem finding on subsequent instruction, the findings could not be conclusive because the posttest instrument had not been subjected to a more rigorous testing and refinement regime with a larger sample size. Hence, this raised a need to address the content and construct validity of this instrument in future investigations.

General Discussion

A pilot study was conducted amongst Primary Four students to gather insights on the kind of problem finding task that might yield optimal student problem finding performance and to determine whether there was an observable difference in terms of problem finding performance and learning outcomes when they engage in different problem finding tasks.

A comparison of the problem finding task results between the same experimental condition groups in both parts of the study (For brevity, part 1 and 2 are hereafter indicated P1 and P2) reveals an interesting observation. Between them, both text with data groups achieved comparable performance in terms of number of questions/problems generated ($M(P1)=5.7$, $M(P2)=5.6$), number of “higher quality” questions ($M(P1)=2.2$, $M(P2)=1.69$) and weighted question quality score ($M(P1)=1.66$, $M(P2)=1.69$). On the other hand, a large variance is observed between both text only groups. The P1 text only group on average

performed much better than those in P2 in number of generated questions ($M(P1)=8.6$, $M(P2)=4.6$), number of “higher quality” questions ($M(P1)=4.5$, $M(P2)=2.1$) with a smaller gap for weighted question quality score ($M(P1)=1.72$, $M(P2)=1.61$).

Bearing in mind three task designs that were tested (text only, text with tabulated data, and text with integrated data), and taking together the finding that the text only group performed better than text with tabulated data group in P1 yet showed less than optimal performance in P2 on quantity and quality of generated problems, we infer that the text with integrated data design yielded the most consistent problem finding performance with sufficiently favorable outcomes in terms of problem quantity and quality.

And on the basis of discernible differences in problem finding performances between groups of students that used structurally dissimilar tasks, we propose that the text with integrated data problem finding task design is adequately suited for subsequent investigations. While our inference would necessarily be limited to those 30 students exposed to paper-and-pen based classroom problem finding activities in this pilot study, it has helped to address the issue on determining a workable design that should be able to generate sufficiently discriminating data in investigations involving other students. For a more robust and nuanced understanding on the relationship between task design and problem finding performance, extensive empirical testing of this and possibly other designs with larger (and different) student groups learning science within varied learning environments is necessary. At the same time, our findings also constitute a set of empirical evidence supporting the idea that students can find problems deemed relevant to a target science concept they had not been formally taught. However, more investigations are required to enlarge the empirical basis to better support any claim on the preparatory benefits of problem finding in promoting conceptual change. Such evidence may be obtained, for example, by adopting a pre-posttest

experimental design and implementing student problem finding activities across multiple classroom lessons on conceptually similar topics.

Conclusion

Motivated by the desire to understand how the efficacy of student problem finding on promoting science classroom learning may be extracted, we carried out an initial study comprising a group of thirty 4th grade students and obtained evidence of their ability to find problems relevant to science concepts they have yet been taught. At the same time, we tested three structurally different problem finding tasks and found that the text with integrated data problem finding task design yielded the most optimal problem finding performance among students. While this pilot may be seen as having achieved its modest two-fold goal of generating an empirical basis to support the case for pre-instructional student problem finding in the primary science classroom and developing a working instrument to trigger problem finding, as with most nascent research, the findings also raised both conceptual and methodological questions that warrant further investigations. Some examples include the efficacy of problem finding if students also generate solutions to their problems, comparison between problem finding and the more commonly used discrepant events as a preparatory activity to promote conceptual change, and the merits and limitations of a paper-and-pen based problem finding task relative to an alternate computer-based task. In some ways, we hope this paper can help inspire both researchers and teachers to explore the problem finding phenomenon in the context of promoting deep and meaningful science classroom learning. We believe there is much untapped potential for productive research that could contribute not only to science education but also the field of cognitive sciences.

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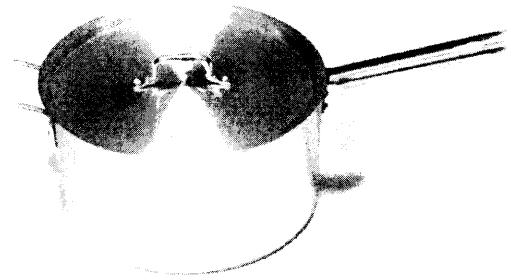
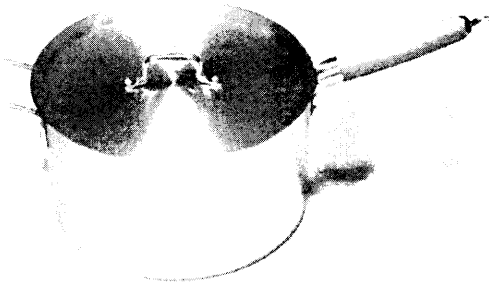
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APPENDIX 1

Pilot Study (Part 1) – Text with tabulated data problem finding task

Effects of heat

Ming and his classmates carried out an experiment that required them to measure the temperature of the handle of two cooking pots. The handle of one pot is made of wood while



the other pot is made entirely of stainless steel.

Pot with wooden handle**Pot with stainless steel handle**

At the start of the experiment, boiling water was carefully poured into both pots. Table 1 shows the temperature measurements recorded by the group at different times during the experiment.

Table 1 Temperature of handle on both pots

Number of minutes	Temperature (°C)	
	Wooden handle	Stainless steel handle
0	27.5	22.0
2	29.0	25.0
4	30.5	29.0
6	33.0	33.5
8	35.0	38.0
10	37.5	41.5
12	39.0	44.5
14	41.0	49.0
16	42.0	55.0
18	42.5	57.0

Your task

Write down as many different Science questions or problems you can think of using the information given on this page.

You do not need to give any answers to the questions or problems you have generated.

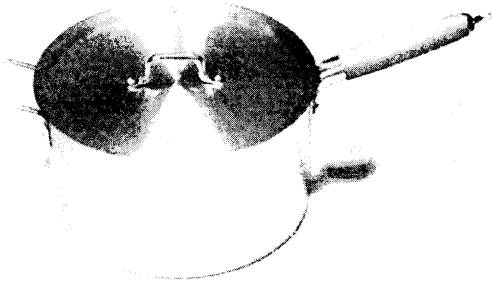
Number each question or problem clearly.

APPENDIX 2

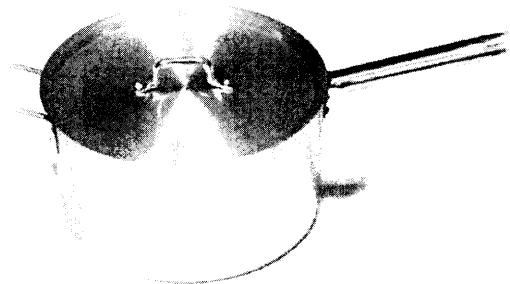
Pilot Study (Part 1) – Text only problem finding task

Effects of heat

Ming and his classmates carried out an experiment that required them to measure the temperature of the handle of two cooking pots. The handle of one pot is made of wood while the other pot is made entirely of stainless steel.



Pot with wooden handle



Pot with stainless steel handle

At the start of the experiment, boiling water was carefully poured into both pots. The temperature of the handle of each pot was measured for 10 times from the start of the experiment.

Your task

1. Write down as many different Science questions or problems you can think of using the information given above.

2. You do not need to give any answers to the questions or problems you have generated.
3. Number each question or problem clearly.

APPENDIX 3

Sample of “higher quality” student generated questions compared to relevant questions on the concept of differential heat transfer between two materials – steel and wood – from Part 1 of the study. Questions are organized according to question words.

Question word	Examples of “higher quality” questions	Examples of relevant questions
What	<ol style="list-style-type: none"> 1. What happens if hot water is put in wooden and steel handle pots? 2. What happens when we hold both pot handles? 	<ol style="list-style-type: none"> 1. What is the highest temperature stainless steel can take? 2. What instrument can be used to record the handle temperature?
Which	<ol style="list-style-type: none"> 1. Which pot will have "more bubbles" if water in a pot with wooden handle and another with steel handle are boiled together? 	<ol style="list-style-type: none"> 1. Which pot can hold the heat long?
Why	<ol style="list-style-type: none"> 1. Why is there a difference in temperature measurements between both handles? 2. Why is metal a good conductor of heat? 	<ol style="list-style-type: none"> 1. Why do both handles become hotter with time? 2. Why record the temperature for a number of minutes after pouring in boiling water?
How	<ol style="list-style-type: none"> 1. How far and fast can heat go? 2. How to make the wooden handle temperature higher than stainless steel handle? 3. How can we make the experiment fail? 	<ol style="list-style-type: none"> 1. How to measure the heat (i.e. temperature) of wooden and steel handles?

APPENDIX 4

Pilot Study (Part 2) – Text with integrated data problem finding task

NOTE: Information and photo in this task have been adapted from 28 September 2013 edition of **TODAY** Online. Original article is accessible at <http://m.todayonline.com/singapore/more-intense-and-frequent-rainfall-expected>

SINGAPORE

More intense and frequent rainfall expected

Reported by NEO CHAI CHIN



Pedestrians seeking shelter from the morning rain...
Photo: Ernest Chua, 26 June 2013.

Singapore and South-east Asia can expect more intense and frequent rainfall events in future, and extreme temperatures that the Singapore currently experiences occasionally could become common.

The Centre for Climate Research Singapore (CCRS) spoke to the **TODAY** after a United Nations (UN) international committee on world climate released its annual climate report. CCRS explained what Singapore could learn from the UN report.

Below are some important points:

By the years 2081 to 2100, average temperature in the Southeast Asia region will rise 3 to 4°C under the most severe situation, and a rise of 0.5 to 1°C under the least severe situation. For Singapore, daily maximum temperature of 34°C that now occurs only about 10 percent of the time (in one year) will occur almost every day by the 2080s. Every 20 years, 25% more rain will fall daily, from 294mm to 367mm. Seawater level at coastal areas (e.g. East Coast Beach) will rise. According to the UN climate report, seawater level around the world may rise 0.26 m to 0.82 m, depending on amount of carbon dioxide produced over the years.

Your task

1. Write down as many *different* Science questions or problems you can think of using the information given here.
2. You do not need to give any answers to the questions or problems you have generated.
3. Number each question or problem clearly.

APPENDIX 5

Pilot Study (Part 2) – Text only problem finding task

NOTE: Information and photo in this task have been adapted from 28 September 2013 edition of **TODAY** Online. Original article is accessible at <http://m.todayonline.com/singapore/more-intense-and-frequent-rainfall-expected>

SINGAPORE

More intense and frequent rainfall expected

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Pedestrians seeking shelter from the morning rain...
Photo: Ernest Chua, 26 June 2013.

Singapore and South-east Asia can expect more intense and frequent rainfall events in future, and extreme temperatures that Singapore currently experiences occasionally could become common.

The Centre for Climate Research Singapore (CCRS) spoke to the **TODAY** after a United Nations (UN) international committee on world climate released its annual climate report. From the UN report, CCRS explained that over the next 70-80 years, the average temperature in the Southeast Asia region will continue to rise. For Singapore, this means that its daily maximum temperature, daily rainfall and seawater level at coastal areas (e.g. East Coast Beach) will also rise.

Your task

1. Write down as many *different* Science questions or problems you can think of using the above information.
2. You do not need to give any answers to the questions or problems you have generated.
3. Number each question / problem clearly.