International Journal of Science Education
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tsed20

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Published online: 03 Mar 2014.

International Journal of Science Education, 2014
http://dx.doi.org/10.1080/09500693.2014.886347

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Although the effects of open inquiry vs. more didactic approaches have been studied extensively, the effects of different types of inquiry have not received as much attention. We examined the effects of guided vs. structured inquiry on secondary students' learning of science. Students from three schools in north-eastern Thailand participated ($N = 239$, Grades 7 and 10). Two classes in each school were randomly assigned to either the guided or the structured-inquiry condition. Students had a total of 14–15 hours of instructions in each condition. The dependent measures were science content knowledge, science process skills, scientific attitudes, and self-perceived stress. In comparison to the structured-inquiry condition, students in the guided-inquiry condition showed greater improvement in both science content knowledge and science process skills. For scientific attitudes and stress, students in one school benefited from guided inquiry much more than they did from structured inquiry. Findings were explained in terms of differences in the degree to which students engaged effortfully with the teaching material.

Keywords: *Guided inquiry; Structured inquiry; Science achievement; Science process skills; Scientific attitudes; Stress*

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The use of inquiry-based approaches is strongly advocated for the teaching and learning of science (Minstrell & van Zee, 2000; National Research Council, 2000; National Science Teachers Association, 2004). The National Research Council (2000), for example, stated that 'inquiry into authentic questions generated from student experiences is the central strategy for teaching science' (p. 29). Which approach to inquiry learning should be adopted in the classrooms is, however, open for debate. A review of the literature reveals a lack of empirical studies that compared different types or levels of inquiry and their impact on science learning. Studies have instead been primarily concerned with comparisons between inquiry-based instruction and more didactic classroom/laboratory methods (e.g. Berg, Bergendahl, Lundberg, & Tibell, 2003; Chang & Mao, 1999; Cobern et al., 2010).

This is one of the first studies to investigate the impact of inquiry learning in Thailand. Despite strong advocacy by the Thai ministry for the use of inquiry learning in science education, our review of the local literature suggests that there is wide discrepancy in how it is implemented. In cases where inquiry learning is used, it is more often inclined towards the structured type. The teaching of science is of particular relevance to Thailand. As a developing country, advancement in science and technology is deemed a key element in economic and social development. Unfortunately, the profile of Thai student in science performance is not at a satisfactory level. A report from the Programme for International Student Assessment in 2009 (Organisation for Economic Co-operation and Development, 2010) showed that Thailand was ranked 47 out of 65 countries. Because of this, science education and research on factors that influence science achievement have gained much attention.

The present study compares two types of inquiry-based approaches: guided vs. structured. The two approaches differed on the amount of explicit instructions given to students. We were specifically interested in their impact on science content knowledge, science process skills, scientific attitudes, and also self-perceived stress.

Inquiry-Based Learning

There are many definitions of inquiry-based learning. Colburn (2000) defined inquiry-based learning as 'the creation of a classroom where students are engaged in essentially open-ended, student-centred, hands-on activities' (p. 42). Martin-Hansen (2002) argued that the types of activities that the students do in inquiry-based learning are close to what actual scientists do in the real world. These include asking questions about the world around them, gathering evidence, and providing explanations. It is generally agreed though that the activities alone do not equate to inquiry learning. For instance, in their paper on inquiry instruction, Bell, Smetana, and Binns (2005) argued that certain hands-on activities that can be found in normal classroom, e.g. building a model of an atom, cannot be referred to as inquiry learning if they are conducted in the absence of research questions.

The inquiry-learning literature tends to be more closely associated with the acquisition of science process skills or 'the thinking patterns that scientists use to construct knowledge' (Chiappetta, 1997, p. 24). Science content knowledge is also deemed an important outcome of inquiry-based approaches with some arguing that content knowledge and process skills are intrinsically linked (Bybee, 1997; Chiappetta & Adams, 2004). One way to conceptualise inquiry-based learning is that it is a student-centric pedagogical approach characterised by activities that encourage the acquisition of both science content knowledge and process skills.

Although definitions differ, researchers typically distinguish between different levels of inquiry-based learning depending on the amount of specific instructions given to students (e.g. Banchi & Bell, 2008; Bell et al., 2005; Buck, Bretz, & Towns, 2008; Colburn, 2000; Herron, 1971; Martin-Hansen, 2002). Bell et al. (2005), for example, used the amount of information given to students to define levels of inquiry. They proposed a four-level model: at the first level, the question, procedures, and solution are all provided to the students. At the second level, the solution is not given. At the third level, both the methods and the solution are not given. At the highest level, information about the question, the procedures, and the solution are all generated by the students.

Similar to previous studies, we operationalised our levels of inquiry in terms of the type of guidance given to students. Our manipulation follows closely the schema proposed by Buck et al. (2008). In our structured-inquiry approach, students were provided with explicit instructions on how to set up the experiment to investigate a pre-defined research question. Under Bell et al. (2005) schema, this condition corresponds most closely to the second level. Laboratory manuals and textbook examples were provided to aid in the analysis and interpretation of results. In the guided-inquiry approach, students were asked to design and set up their own experiment and to answer a pre-defined research question. However, no laboratory manual or textbook examples were provided during this process. This condition corresponds most closely to Bell et al.'s third level or to what Buck et al. refers to as open inquiry.

Inquiry in the Classroom

There is little consensus on which and how different levels of inquiry should be implemented in the classroom. Some believe in a natural progression from forms of inquiry that include structured procedure and explicit teachers' instruction to more open forms (Akerson & Hanuscin, 2007; Cuevas, Lee, Hart, & Deaktor, 2005; Edelson, Gordin, & Pea, 1999; Lee, 2012); the zenith of which is probably Bell et al.'s (2005) level four. Although there are reported learning benefits from an open-inquiry approach (e.g. Berg et al., 2003), there are numerous difficulties associated with its implementation: teachers' preparedness (Shedletzky & Zion, 2005), teachers' fear of losing classroom control (Deters, 2004), and students' frustration (Trautmann, MaKinster, & Avery, 2004) being some of them. For these reasons, the provision of some explicit procedures and instruction has the potential to mitigate some of these problems and facilitate the implementation of inquiry learning. There are some evidence suggesting that forms of inquiry that include some explicit instructions are more effective in imparting science content knowledge and science process skills compared to expository or verification laboratories (e.g. Blanchard et al., 2010). It is also believed that such forms of inquiry provide learning opportunities comparable to those of open inquiry (Gaddis & Schoffstall, 2007).

Although there is an extensive empirical literature comparing inquiry approaches against non-inquiry-based approaches, there are only a few studies that focused on differences among various levels of inquiry. Chatterjee, Williamson, McCann, and Peck (2009) investigated university students' attitudes towards guided-inquiry laboratories and open-inquiry laboratories. The students were all enrolled in a semester long chemistry course in which students conducted both guided- and open-inquiry experiments. They found that most students preferred inquiry laboratories in which some instructions and procedures were provided instead of open-inquiry laboratories. Sadeh and Zion (2009) studied two groups of high school biology students. One group was exposed to an open-inquiry environment, while the other group was taught using an inquiry approach in which instructions and procedures were provided. They assessed students' inquiry performances according to four criteria: 'changes occurring during inquiry', 'learning as a process', 'procedural understanding', and 'affective points of view'. They found that the open-inquiry group outperformed their peers on 'procedural understanding'. In a more recent study, Sadeh and Zion (2012) surveyed two groups of high school biology students who were engaged in an inquiry project which lasted two years. They reported that 'open inquiry students were more satisfied and believed that they gained benefits from implementing the project, to a greater extent than guided inquiry students' (p. 838). Note that the guided inquiry used in Sadeh and Zion (2012) differs from that used in our study. Students in the guided-inquiry condition in our study were not provided with specific instructions on the procedure they should use.

Given the dearth of existing studies and the possibilities that different levels of inquiry may have different effects on different criterion measures, we examined the effects of guided vs. structured inquiry on science achievement, scientific attitudes, and stress. Students in the guided condition were expected to learn more compared to their peers in the structured condition who were engaged in a relatively more passive form of learning. It was also expected that students in the guided condition would develop better scientific attitudes. With regard to stress, we speculated that students in the guided condition would experience higher levels of stress because they received less explicit instructions than students in the other group. However, it is possible that the learning process in the guided condition would be perceived as being more enjoyable, which may result into lower levels of stress being reported.

Method

Design and Participants

The study was based on a 2 (pedagogical condition: guided inquiry vs. structured inquiry) × 2 (time of measure: pretest vs. posttest) × 3 (School: 1 vs. 2 vs. 3) design. Participants' science process skill, science content knowledge, scientific attitudes, and stress were measured both before and after interventions. A total of 239 participants (male = 98) from six classrooms in three secondary schools in the Northeast of Thailand were recruited. The participants were from Grade 10 ($M_{age} = 15.45$, SD = 0.520; School A, $N = 86$; School B, $N = 97$) and Grade 7 ($M_{age} = 13.56$, SD = 0.48; School C, $N = 56$). Two classes in each school were randomly assigned to either the guided-inquiry or structured-inquiry group. Grade 10 was chosen because it is the first year of upper secondary education. With the pressure of end of school examination further away, teachers at this grade are typically more receptive to alternative forms of pedagogy. Recruiting from two schools provided us an opportunity to examine the generalisability of findings. Obviously, more schools would have allowed us to better delineate teacher and school-related effects. Unfortunately, we were hampered by logistical constraints.

The main stream Thai education system uses a 6–3–3 sequence from primary to secondary school. However, some primary schools have experimented with an expanded curriculum to include the lower secondary years (Grades 7–9). In the past, some of these schools have suffered from a lack of qualified staff for the lower secondary segment. Although some of these earlier problems have been ameliorated, some concerns regarding quality remain. In this study, we included one of such schools as a pilot evaluation of the feasibility of including guided inquiry in the curriculum.

Pedagogical Manipulation

The 5E Learning Cycle Model (Bybee, 1997) was used to develop our instructional conditions. This model was chosen because it has been widely used in the literature and in actual classrooms. It is also the model recommended by the Thai Ministry of Education. In brief, the 5E Learning Cycle is a model of learning which consists of five phases: Engagement, Exploration, Explanation, Elaboration, and Evaluation (see Appendix 1 for an example). More detailed description of the five phases, as implemented in the structured and guided conditions, are given below. Classes in both conditions used a similar structure in that teachers began with a process that encouraged students to ask questions, this then flowed on to the students running investigations, collecting and analysing data, and drawing conclusions about the outcomes. In the present study, the two instructional conditions differed at the Engagement, Exploration, and Explanation phases. Much of the pedagogical manipulation occurred in the last two phases as they provided the most opportunity for students to act independently. We developed four lessons plans in total—two for each grade and one for each of the instructional conditions. Teachers were instructed to follow the lessons plans as closely as possible.

Structured inquiry. The Engagement phase served as an initial introduction to the topic to be investigated. In this first phase, students interacted with concrete materials and are asked by the teachers to make specific observations regarding the material. The teacher then proceeded to the next phase. In the Exploration phase, students underwent pre-laboratory training led by the teacher. In this training, the teacher described in detail the procedures for the laboratory activity to be conducted. For example, in an experiment investigating elastic potential energy, Grade 10 students were given the following instructions on how to set up a spring coil and take measurements (see Appendix 1 for the complete lesson plans):

(1) Secure one end of a spring coil and hook a spring scale to the other end of the coil. Place a ruler parallel to the apparatus. The end of the spring coil which is hooked to the spring scale should be at the zero point of the ruler.
(2) Pull the spring scale until the distance stretched is 1, 2, 3 cm, … Read the amount of force from the scale for each trial. Record the amount of force and the distance stretched.
(3) Plot the graph with the amount of force on the *y*-axis and the distance stretched on the *x*-axis.

After setting up the apparatus, students performed the experiment and analysed the data according to the prescribed procedures. In the Explanation phase, students were asked to prepare a presentation on the results of their experiment. Their presentation was done in front of the whole class. Students were aided in the preparation of their presentations by information provided in the textbook. An example of the type of information given is as follows (see Appendix 2 for the full version):

> Objects around us move in many different ways. Fruits falling from a tree move in a straight line or have linear motion. When a ball is thrown out horizontally, it moves along a curve or has a curve motion. A curve motion also happens when you throw a basketball in the hoop. When you sit on a playground swing, you will move back and forth following the arc of a circle. These examples show that many moving objects follow either a linear or a curve path.

In the Elaboration phase, the teacher asked the students to answer a prepared set of applied questions that related directly to the topic of their previous investigation. In the Evaluate phase, the teacher observed and took notes of the students' discussion, how they answered questions, and how they conducted the actual experiment. The Evaluate phase was not an independent phase which occurred sequentially after the Elaboration phase. The teacher monitored students' activities throughout the other phases. In other words, the Evaluation phase occurred concurrently with other phases. If there were any questions from the students during any of the phases, the teacher would either repeat the same instructions given previously or the information found in the textbook.

Guided inquiry. The Elaboration and Evaluation phases remained unchanged and were the same as the structured-inquiry condition. In the Engagement phase, teachers using guided inquiry differed in their approach in that they encouraged the students to come up with and ask their own questions. However, if their students failed to come up with any question, the teachers would help by injecting some questions, which can sometimes be similar to those found in the textbook. In the Exploration phase, students were led through some background discussion on the topic, but were not given any specific instructions on how to design an experiment to study the issue. Students were provided with key research questions and were asked to devise an experiment to answer those questions. Without giving any other specific instructions or aid, they were also asked to analyse their data and draw their own conclusions. In the Explanation phase, students were again not given any aid in preparing the presentation. During the presentation to the class, the teachers took a more active role and asked questions if the students did not touch on specific ideas deemed essential for the topic of interest. In any of the phases, if there were any questions from the students, the teachers would encourage students to come up with their own answers instead of giving them specific instructions. An example of the kind of teacher–student interaction that occurred in this condition is as follows:

> Teacher: Has any group not finished designing their experiment?
> Student: We would like to study circular motion, but we don't know how to design the experiment.
> Teacher: Which object would you like to study? Which object or tool would you like to study? Choose one of the tools.
> (The students choose a ball and a yarn)
> Teacher: Try to make the ball move in a circle. How would you do it?
> (One of the students swing her hand over the head; another student makes the ball moves in a circle in front of him)

Instruments

Science content knowledge. The science content knowledge test was a 40-item, teacher constructed, multiple choice test. This test contained questions which are typically found in most standard school examinations. All test questions (52 items for Grade 10 and 71 items for Grade 7) were evaluated for validity by three expert science educators. Some items were deleted based on their expert judgements. After that, we piloted the instrument and deleted some additional items because they did not meet the discrimination (more than 0.2) or difficulty index (0.2–0.8). Reliability (KR20) of the Grade 10 and Grade 7 instruments was 0.92 and 0.90, respectively.

Science process skills. An adaptation of the science process skills test used in Takham (2002) was administered. The test assessed 13 different science process skills including the ability to formulate hypotheses, to interpret data, and to draw conclusion (e.g. What should be measured if a researcher would like to know whether driving at different speeds would result in different amount of fuel being consumed?) This test is similar to the 'procedural understanding' criterion used in the assessment of dynamic inquiry in Sadeh and Zion (2009). The whole test consisted of 45 multiple choices items (KR20 = 0.86).

Scientific attitudes. The scientific attitudes rating scale was adapted from Wongsue (2004). The task was administered to assess whether students' scientific attitudes improved at the end of the inquiry lessons. The task contained items designed to evaluate six traits: curiosity (e.g. I read science magazines), reasonableness (e.g. I believe that people's lives are determined by fate), responsibility and perseverance (e.g. if I am given an easy task, I do it immediately but if the task is very difficult, I will pass it to someone else), organisation and carefulness (e.g. I check the apparatus before doing experiment), honesty (e.g. even if my results are not as same as another group, I will not change it), and open-mindedness (e.g. I am willing to listen to the opinions of others even if they do not agree with mine). The original version had 45 items with Cronbach's $\alpha = .92$. Some items were deleted as they did not meet the discrimination index when the instrument was piloted. The final version contained 25 items ($\alpha = 0.72$).

Stress. The self-perceived stress rating scale used in this study was developed by the Department of Mental Health (1998). It contained 20 items and targeted symptoms in the following domains: physical (e.g. having a migraine or temporal pain on both sides), emotion (e.g. feeling emotionally disturbed and frustrated), mind (e.g. my life is not valuable), and behaviour (e.g. I do not want to meet people). The participants provided self-evaluation based on the past two months on a four-level Likert scale.

Procedure

Students completed all the instruments as a pretest the week prior to the start of intervention. During intervention, the teachers in Grade 10 met their class and implemented the teaching experiment twice a week, two hours per session, for a total of 14 hours. Grade 7 students met their teacher three hours a week. They had a one-hour session and a two-hour session, for a total of 15 hours. For both grade levels, a new topic or investigation was covered within the span of one session. Grade 10 students studied a total of seven topics related to work and energy and Grade 7 students studied a total of 10 topics related to motion. For the Grade 7 students, the lengthier topics were taught in the two-hour sessions, while the shorter topics were covered in the one-hour sessions. One week after the intervention, students were assessed on the various outcome measures.

Both the structured and guided groups in each school were taught the same content for four weeks by the same teacher. A different teacher taught in each school. All three teachers were female, with bachelor degrees in Physics and science teaching licences. However, they had different amount of experience in teaching. The Grade 7 teacher had taught science at that level in the same school for three years. One Grade 10 teacher had taught Physics at that level in her school for six years and the other had only two years of experience.

Results

Demographic data suggested that there were no significant differences in the gender ratio, age, and prior science grade across the control and experimental classes in all three schools (see Table 1).

The data were analysed using a 2 (pedagogical condition: guided vs. structured) × 2 (gender) × 3 (school) × 2 (time of test: pretest vs. posttest) multivariate analysis of variance. Scores from the science content knowledge, science process skills, and scientific attitude tests served as dependent variables. Measure of stress was also included as a dependent measure. Because implementation of the study in the various schools were hampered by logistical constraints and we were unable to implement a fully crossed factorial design containing different schools and grades, we grouped data from all three schools under the same independent variable rather than using a more complicated nested design. For similar reasons, we did not include the quaternary interaction in the analysis.

Table 1. Participant characteristics

School 1 (Grade 10)						
	Guided $N = 42$ (males = 17)		Structured $N = 44$ (males = 12)			
Measure	M	SD	M	SD	t	p
Age	15.71	0.52	15.84	0.52	1.15	0.13
Prior science grade	2.72	0.58	2.52	0.68	1.46	0.07
School 2 (Grade 10)						
	Guided $N = 49$ (males = 21)		Structured $N = 48$ (males = 19)			
Measure	M	SD	M	SD	t	p
Age	15.51	0.50	15.62	0.49	1.14	0.13
Prior science grade	2.60	0.69	2.59	0.51	0.05	0.48
School 3 (Grade 7)						
	Guided $N = 27$ (males = 15)		Structured $N = 29$ (males = 15)			
Measure	M	SD	M	SD	t	p
Age	13.14	0.39	13.19	0.32	0.57	0.57
Prior science grade	3.18	0.75	3.16	0.54	0.50	0.63

Notes: The t- and p-values reported refer to the t-tests conducted to check for group differences (guided vs. structured) in age and prior science grade. Results are segregated by grade level. No significant differences were found for all comparisons ($p < .01$).

The main effects were of pedagogical condition, time of test, and school attained significance, but there were no gender-related differences. All three significant main effects were qualified by secondary effects involving each other. These were, in turn, qualified by a tertiary interaction effect, $F(8, 456) = 8.63$, $p < .001$, partial $\eta^2 = .13$. Inspection of the univariate findings shows that the attitude and stress measures were most strongly affected by the tertiary interaction effect. Science content knowledge and science process skills were affected by secondary interactions involving (a) time of test and pedagogical condition and (b) time of test and school.

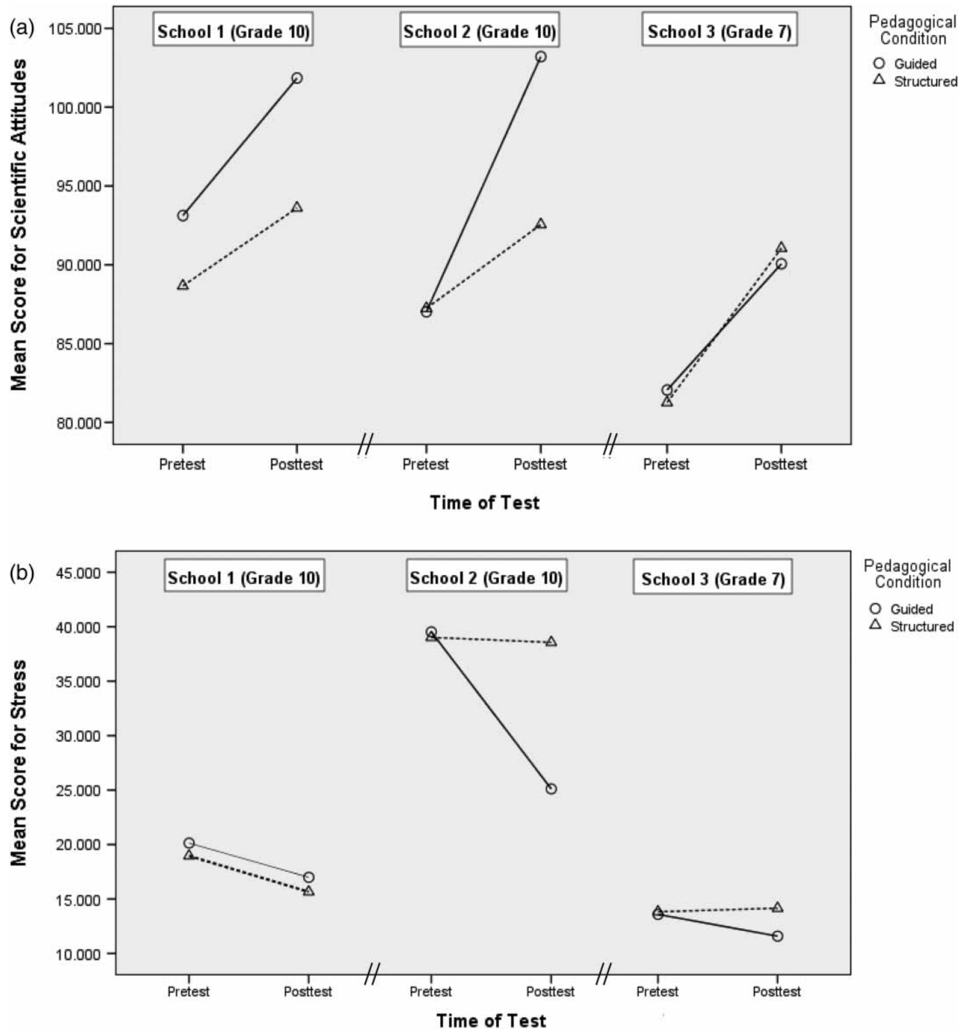


Figure 1. Tertiary interaction effects of pedagogical condition, time of test, and school on attitude (top panels) and stress (bottom panels).
Note: For easier comparison individuals plots for each of the measures have been combined into one single figure with the labels being repeated on the *x*-axis

For the tertiary interaction involving attitude and stress, we conducted follow-up tests by examining the effects of the pedagogical intervention in each of the three schools separately. There were notable differences in the pattern of findings across the three schools (see Figure 1). In School 1, there was a significant secondary interaction involving pedagogical condition and time of test on attitude. In School 2, both attitude and stress were affected by a secondary interaction effect, but in different ways. In both schools, there was significant improvement in attitude from pretest to posttest in both the guided-inquiry and structured-inquiry groups. Inspection of effect sizes showed greater improvement in the guided-inquiry group than in the structured-inquiry group. This was particularly notable in School 2 ($\eta^{2=}$ .68 in the guided-inquiry group vs. .18 in the structured condition). For the stress measure, stress decreased equally in both pedagogical conditions in School 1. A strong differential effect was found in School 2 in which stress level decreased in the guided inquiry, but not in the structured-inquiry condition. In School 3, neither the stress nor the attitude measure was affected by the secondary interaction. For this school, the only significant effect was the main effect of the time of test on attitude, $F(1, 54) = 12.29$, $p = .001$, partial $\eta^2 = .19$. There was an improvement in attitude from pretest to posttest, but this improvement was not affected by the pedagogical condition to which the children were assigned.

The science content knowledge and science process skills measures were affected by an interaction effect involving time of test and pedagogical condition (see Figure 2). For science skills, we found the same pattern across all three schools. There were significant improvements in skill in both pedagogical conditions, but improvement in the guided-inquiry condition ($\eta^{2=}$ .74) was larger than that was found in the structured-inquiry condition ($\eta^{2=}$ .58). We found a similar pattern for science

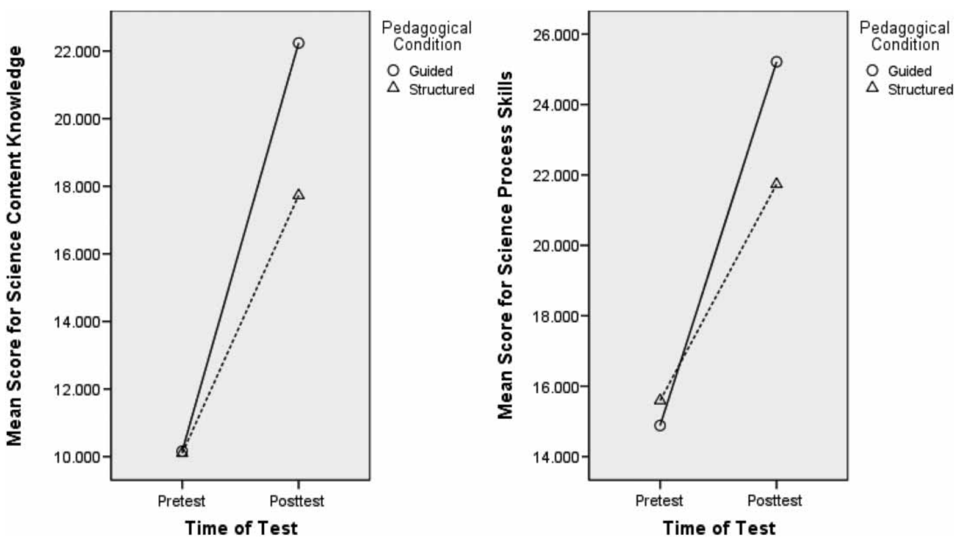


Figure 2. Secondary interaction effects of pedagogical condition and time of test on science content knowledge (left panel) and science process skills (right panel)

Table 2. Descriptives for the outcome measures

		Science process skill				Science content knowledge				Scientific attitudes				Stress			
		Pretest		Posttest		Pretest		Posttest		Pretest		Posttest		Pretest		Posttest	
School	Condition	*M*	SD	*M*	SD	*M*	SD	*M*	SD	*M*	SD	*M*	SD	*M*	SD	*M*	SD
School 1 (Grade 10)	Guided	20.81	6.22	30.24	5.29	10.26	3.57	26.33	3.03	93.41	7.62	100.91	7.16	20.31	7.73	16.64	8.24
	Structured	22.09	4.14	27.07	3.30	10.73	2.07	22.18	4.33	88.98	6.29	93.55	6.60	18.80	8.06	15.59	5.47
School 2 (Grade 10)	Guided	13.29	7.25	26.12	3.50	10.76	3.84	21.47	2.44	87.18	9.11	102.65	12.36	39.63	6.81	24.90	3.68
	Structured	14.31	6.43	21.96	2.54	11.04	2.53	16.44	3.30	87.31	8.07	92.54	11.70	38.98	5.84	38.54	5.38
School 3 (Grade 7)	Guided	8.56	2.46	15.74	2.61	8.93	3.23	17.26	1.58	82.00	11.87	90.26	12.78	13.56	4.21	11.67	4.01
	Structured	7.86	1.79	13.28	2.22	7.59	2.57	13.10	2.40	81.21	12.96	91.07	10.23	13.86	6.23	14.17	5.19

content knowledge, but the difference in effect size between the two pedagogical conditions was smaller (η^{2} = .85 and .70 for the guided-inquiry and structured-inquiry conditions, respectively). The same measures were also affected by an interaction involving time of test and school. Because this interaction did not involve pedagogical condition, it was not of particular interest. In all schools, children performed better in the posttest than in the pretest. The interaction reflected differences in the average performance levels across schools (see Table 2).

Discussion

In all three schools, students who were exposed to a more open form of inquiry—guided inquiry—showed greater improvements on the science content and science process skills measures compared to their peers who were taught using a more limited form of inquiry. This is consistent with the findings from Sadeh and Zion (2009) and suggests that a guided-inquiry approach is more effective than a structured-inquiry approach in imparting science content knowledge and science process skills. The literature on inquiry-based vs. traditional laboratory instruction provides some plausible explanation for the efficacy of the guided-inquiry approach. Stewart (1988) argued that faced with more traditional laboratory instructions, students might be more concerned about getting the correct results than the process of experimentation per se. In the context of our study, students in the structured-inquiry group might have been more focused and worried about following the procedures given by the teacher and specified in the textbook than more meaningful learning. Commenting on the restrictive nature of traditional laboratories, Domin (1999) argued that 'traditional laboratory activities are designed to facilitate the development of lower-order cognitive skills such as rote learning and algorithmic problem solving' (p. 544). Such a focus may have handicapped the student's performance on the content and process skills measures.

Compared to structured inquiry, the guided-inquiry condition is engineered to include more flexibility in the kind and amount of information provided by the teachers. Although, at times, teachers provided as much if not more information in the guided than in the structured condition, the information is more contextualised to the uncertainty expressed by the students. Students are also encouraged to engage, think about, and explain the phenomena they observe. In the cognitive literature, it is well established that more effortful processing leads to better retention of information (e.g. Craik & Tulving, 1975). In this study, students in the guided-inquiry condition had to come up with their own procedures and analyse their experiment. On the other hand, students in the structured-inquiry condition received explicit instructions on how to conduct the experiment and had access to information from the laboratory manual and the textbook. Arguably, students in the guided-inquiry condition had to engage with the information more deeply. It is perhaps this kind of more effortful processing that allowed them to perform better in both the achievement and skills assessment. Nonetheless, it should be noted that students in the structured-inquiry group still showed significant improvements on both measures suggesting that even structured inquiry is still effective in science classrooms.

In terms of promoting scientific attitudes, a similar pattern of results was observed. Students in the guided-inquiry group showed greater improvements compared to their peers in the structured-inquiry group. This is perhaps not surprising as students in the guided-inquiry group had more opportunities to engage in scientific processes. For instance, in developing the procedures for their investigation, students had to reflect on what they were doing and to ask questions. This is similar to what graduate scientists do. Because students' experiences in the structured-inquiry group were highly structured, they had fewer opportunities to engage in such activities. An interesting finding was that the effect of instructional condition on improvement in scientific attitudes was observed amongst the Grade 10, but not the Grade 7 students. For the Grade 7 students, both instructional conditions resulted in similar increases in scientific attitudes. Because their pretest attitude scores were somewhat lower than the older children, these findings suggest that a certain level of maturity or pre-existing attitude may be needed before students can obtain the optimal benefits from guided inquiry.

A significant decrease in self-perceived stress was observed for both instructional conditions, but only for the Grade 10 students. Furthermore, we found a larger decrease in stress levels in the guided-inquiry group compared to the structured-inquiry group in one of the Grade 10 schools. One possible explanation for this finding is that it is an artefact of pretest differences in stress level. The school that exhibited the larger decrease in the guided-inquiry condition had a much higher pretest stress level than the other Grade 10 schools. We do not know the reason for this pretest difference, but the finding suggests that a guided-inquiry approach seems to be an effective strategy for decreasing self-perceived stress. This may have, in turn, produced the better learning outcomes. To test this hypothesis, we re-ran our analysis using pretest stress levels and change in stress levels as covariates. The pattern of findings related to our pedagogical manipulation remained the same, suggesting that differences between the effects of guided vs. structured inquiry are not contingent on or affected by self-perceived stress level.

Limitations

As with most teaching experiments, logistical constraints made random assignment to group impracticable. For this reason, the findings are affected by a confound between teachers and schools. This may have affected the results in two ways. First, teachers in the three schools have somewhat different teaching experiences. This may have affected the children's responses. Fortunately, in each school, the guided- and structured-inquiry conditions were implemented by the same teacher. Thus, though overall performances may have differed across schools, we were able to minimise teacher-related influences across the two pedagogical conditions.

A related concern is that data were analysed using a conventional analysis of variance design that did not take account of the fact that children were from intact classroom. Ideally, a multi-level analysis would have allowed us to segregate variance attributable to the individual, teacher, or school level. However, with only three teachers from three schools, there was insufficient sampling at the teacher or school level to model their influences effectively. This is an issue that needs to be addressed in future studies.

Second, two of our teachers taught Grade 10 students and the other taught Grade 7. As such school-based differences are confounded by both the age of the children and differences in topics covered. We have taken this issue into account in interpreting the findings, but given that there are significant differences in findings across schools, the possibility that guided inquiry may be more effective for some age groups or some topics should be explored more systematically in future studies. A final concern is that there are multiple differences between the guided and structured conditions. Although the same content was taught, there were differences in the engagement, exploration, and explanation phases. Because the various changes were part and parcel of each condition, we are unable to determine whether changes at any one stage are more important.

Conclusions

Our findings suggest that a more open form of inquiry is more beneficial to students. From a teacher training perspective, these findings provide further evidence in support of the need to develop teachers' abilities to deliver and guide students using a guided-inquiry approach. Even with adequate teacher preparation, this is not an easy undertaking as guided-inquiry lessons typically require more time to implement. Teachers using this approach are often anxious as they feel they will not have time to finish all the content required in curriculum. However, this is not a problem unique to Thailand or to science education and will require careful balancing between the need to develop science content knowledge, science process skills, and scientific attitudes.

Acknowledgements

This article is based on work conducted by the last three authors for their master degree in science education at Khon Kaen University. The studies were partially supported by Khon Kaen University under the Incubation Researcher Project and by the Higher Education Research Promotion and National Research University Project of Thailand, Office of the Higher Education Commission, through the Cluster of Research to Enhance the Quality of Basic Education. We thank all the students who participated in this study.

References

Akerson, V. L., & Hanuscin, D. L. (2007). Teaching nature of science through inquiry: Results of a 3-year professional development program. *Journal of Research in Science Teaching*, *44*(5), 653–680.

Banchi, H., & Bell, R. (2008). The many levels of inquiry. *Science and Children*, *46*(2), 26–29.

Bell, R. L., Smetana, L., & Binns, I. (2005). Simplifying inquiry instruction. *The Science Teacher*, *72*(7), 30–33.

Berg, C. A. R., Bergendahl, V. C. B., Lundberg, B., & Tibell, L. (2003). Benefiting from an open-ended experiment? A comparison of attitudes to, and outcomes of, an expository versus an open-inquiry version of the same experiment. *International Journal of Science Education*, *25*(3), 351–372.

Blanchard, M. R., Southerland, S. A., Osborne, J. W., Sampson, V. D., Annetta, L. A., & Granger, E. M. (2010). Is inquiry possible in light of accountability?: A quantitative comparison of the relative effectiveness of guided inquiry and verification laboratory instruction. *Science Education*, *94*(4), 577–616.

Buck, L. B., Bretz, S. L., & Towns, M. H. (2008). Characterizing the level of inquiry in the undergraduate laboratory. *Journal of College Science Teaching*, *38*(1), 52–58.

Bybee, R. W. (1997). *Achieving scientific literacy: From purposes to practices*. Portsmouth, NH: Heinemann.

Chang, C.-Y., & Mao, S.-L. (1999). Comparison of Taiwan science students' outcomes with inquiry-group versus traditional instruction. *The Journal of Educational Research*, *92*(6), 340–346.

Chatterjee, S., Williamson, V. M., McCann, K., & Peck, M. L. (2009). Surveying students' attitudes and perceptions toward guided-inquiry and open-inquiry laboratories. *Journal of Chemical Education*, *86*(12), 1427–1432. doi:10.1021/ed086p1427

Chiappetta, E. L. (1997). Inquiry-based science. *The Science Teacher*, *64*(7), 22–26.

Chiappetta, E. L., & Adams, A. D. (2004). Inquiry-based instruction: Understanding how content and process go hand-in-hand with school science. *The Science Teacher*, *71*(2), 46–50.

Cobern, W. W., Schuster, D., Adams, B., Applegate, B., Skjold, B., Undreiu, A., ... Gobert, J. D. (2010). Experimental comparison of inquiry and direct instruction in science. *Research in Science & Technological Education*, *28*(1), 81–96.

Colburn, A. (2000). An inquiry primer. *Science Scope*, *23*(6), 42–44.

Craik, F. I., & Tulving, E. (1975). Depth of processing and the retention of words in episodic memory. *Journal of Experimental Psychology: General*, *104*(3), 268–294.

Cuevas, P., Lee, O., Hart, J., & Deaktor, R. (2005). Improving science inquiry with elementary students of diverse backgrounds. *Journal of Research in Science Teaching*, *42*(3), 337–357.

Department of Mental Health. (1998). Bab wad kwam kread suan prung 20 [Suanprung Stress Test-20]. Retrieved February 3, 2014, from http://www.dmh.go.th/test/stress/

Deters, K. (2004). Inquiry in the chemistry classroom. *The Science Teacher*, *71*(10), 42–45.

Domin, D. S. (1999). A review of laboratory instruction styles. *Journal of Chemical Education*, *76*(4), 543–547.

Edelson, D. C., Gordin, D. N., & Pea, R. D. (1999). Addressing the challenges of inquiry-based learning through technology and curriculum design. *Journal of the Learning Sciences*, *8*(3–4), 391–450.

Gaddis, B. A., & Schoffstall, A. M. (2007). Incorporating guided-inquiry learning into the organic chemistry laboratory. *Journal of Chemical Education*, *84*(5), 848–851.

Herron, M. D. (1971). The nature of scientific enquiry. *The School Review*, *79*(2), 171–212.

Lee, V. S. (2012). What is inquiry-guided learning? *New Directions for Teaching and Learning*, *2012*(129), 5–14.

Martin-Hansen, L. (2002). Defining inquiry: Exploring the many types of inquiry in the science classroom. *Science Teacher*, *69*(2), 34–37.

Minstrell, J., & van Zee, E. H. (Eds.). (2000). *Inquiry into inquiry learning and teaching in science*. Washington, DC: American Association for the Advancement of Science.

National Research Council. (2000). *Inquiry and the national science education standards: A guide for teaching and learning*. Washington, DC: National Academy Press.

National Science Teachers Association. (2004). *NSTA position statement*. Retrieved from http://www.nsta.org/pdfs/PositionStatement_ScientificInquiry.pdf

Organisation for Economic Co-operation and Development. (2010). *Programme for international student assessment. 2009 results*: Executive summary. Retrieved from http://www.oecd.org/pisa/pisaproducts/46619703.pdf
Sadeh, I., & Zion, M. (2009). The development of dynamic inquiry performances within an open inquiry setting: A comparison to guided inquiry setting. *Journal of Research in Science Teaching*, *46*(10), 1137–1160.
Sadeh, I., & Zion, M. (2012). Which type of inquiry project do high school biology students prefer: Open or guided? *Research in Science Education*, *42*, 831–848.
Shedletzky, E., & Zion, M. (2005). The essence of open-inquiry teaching. *Science Education International*, *16*(1), 23–38.
Stewart, B. Y. (1988). The surprise element of a student-designed laboratory experiment. *Journal of College Science Teaching*, *17*(4), 269–270.
Takham, P. (2002). *Effect of using activity packages for science process skills enrichment of lower secondary school students* (master's thesis). Master in Science Education, Chiang Mai University, Chiang Mai, Thailand.
Trautmann, N., MaKinster, J., & Avery, L. (2004, April). *What makes inquiry so hard? (and why is it worth it?)*. Paper presented at the 77th annual meeting of the National Association for Research in Science Teaching, Vancouver, BC, Canada.
Wongsue, R. (2004). *A study of scientific attitude and science process skills of Mathayomsuksa 1 students in Samutsakhon province* (master's thesis). Bangkok, Thailand: King Mongkut's Institute of Technology Ladkrabang.

Appendix 1. Grade 10 lesson plan on elastic potential energy for guided- and structured-inquiry groups (translated from Thai)

Core concept

Elastic potential energy is potential energy stored as a result of deformation of an elastic object, such as the stretching of a spring. It is equal to the work done to stretch the spring. Since the force has a form $F = -kx$, the work done to stretch the spring distance x is $W = E = (1/2)\ kx^2$.

Expected Learning Outcomes

The students should be able to:

1. Explain the meaning of elastic potential energy
2. Find the relationship between the size of the force that pull the spring and the distance of spring stretch and should be able to conclude that the distance of spring stretch vary by the amount of the force that pull the spring
3. Give examples of elastic potential energy and how to benefit from it in everyday life.
4. Calculate the elastic potential energy of the spring when given spring constant and stretched distance from equilibrium position

Content

The following concept is central to this topic:

When we push or stretch the spring with our hands we will notice that there is force acting on our hands. This force brings the spring back to the original position. This shows that there is an energy stored in the compressed or stretched spring and this energy is transformed into kinetic energy to bring the spring back to the original position. The energy stored as a result of deformation of an elastic object, such as a spring, is called elastic potential energy. It is equal to the work done to stretch the spring distance x, so $E = (1/2)\ kx^2$, where E = elastic potential energy, x = the distance by which the spring is stretched or compressed, and k = spring constant = force that stretch the spring distance one unit of length.

Learning Activities

Structured Inquiry	Guided Inquiry
Engagement 1. Give a big elastic band to one student to stretch it and asks for his observation while doing it. Hold a discussion with the students until they derive the concept that if we want to stretch more distance, we have to use more force. Also, that there is a force to bring the elastic back to its previous position.	**Engagement** 1. Teacher shows stimuli to students and asks four students to come to the front of the class and press each of four objects (a sponge, inflated balloons, play-dough, and a spring) 2. Teacher asks the students to explain what occurs when each object is compressed and released. The discussion continues until students realise that: "When there is a force acting on objects like sponges, balloons, or springs, the shape of these objects are changed, and when they are released, the shape of each object goes back to its initial status. But it is not the same with the clay, when there is a force on the clay, its shape changes, and it does not go back to its initial shape." 3. Teacher provides the following information: "some objects (sponges, balloons, springs) have a property that we called 'elasticity', which allow them to go back to their initial shape when we release them. Other objects do not have this property. Today, we will focus only on elastic objects".
Exploration 1. Each group studies the lab direction from text book and conducts the experiment 2. Each group was given a worksheet as follows: Worksheet	**Exploration** 1. Teacher shows some elastic bands and asks the students to think about the utility of elasticity by showing the picture in Figure 3. Teacher asks the students to think about how to use catapults to shoot marbles as far as possible. The expected answer is to use more force to stretch the elastic further.

Objective :

Find the relationship between force and stretched distance

Materials :

1. A spring scale
2. A spring coil
3. A ruler

Method :

1. Based one end of a spring coil and use the spring scale hook the other end. Put both the spring coil and the spring scale laid in parallel with the ruler, the end of the spring coil which hooked by the spring scale must be at the zero point of the ruler.
2. Pull the spring scale until it stretch distance is 1,2,3,… cm. Read the amount of force from the scale for each trial. Record the amount of force and the stretch distance.
3. Plot graph between the amount of force in Y-axis and the stretch distance in X-axis

Data Recorded :

Table

Stretched distance cm	0	1	2	3	4	5	6	7
Amount of force N								

Data analysis and Discussion

Plot your graph here

1. Describe your graph.
2. What is the relationship between the amount of force and the distance stretched?

Conclusion :

Figure 3

2. Teacher then asks "while we stretch the elastics, is any energy involved?" When the students agree that there is an energy, teacher gives the information that this energy is called "elasticity potential energy"
3. Teachers shows Fig.5 and asks the students to explain the difference between the situations of object A and object B, including to clarify about the forces upon each object and discuss about the gravitational potential energy until reaching the concept that it should be another energy which should be called "elasticity energy of the spring"

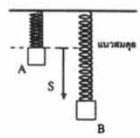
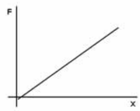
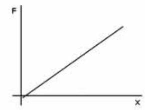


Figure 5

4. Teacher further describes that in this figure, the mass B was moved down by gravitational potential energy, and this energy transforms to become elasticity energy. So the potential energy in the elastic object should be called elasticity potential energy.
5. Teacher asks the students to work in group of 5 - 6 persons to design an experiment to answer the question "What is the relationship between the amount of force and the stretched distance of the elastic?" Each group has to formulate the hypothesis and design the experiment, and think about how to collect and record data; form a conclusion and discuss the results.
6. A worksheet was prepared for them.

	Worksheet **Question** : What is the relationship between the amount of force and the stretched distance of the elastic? **Related science concept**: When there is a force upon a spring, the spring will stretch, but the spring itself has an elasticity force that pulls it back to its previous position. **Material**: 1. A spring scale 2. A spring coil 3. A ruler 4. ……………………… 5. …………………………. 6. …………………………. **Experiment** : (Write your design here)

	Data Recorded : (Design your table and graphing here) **Analysis of data** : **Discussion :** **Conclusion :**
Explanation 1. Asks some groups to explain their results in front of the class. Ask the students to conclude their experiment and answer the after lab questions in the textbook 2. Students explain elasticity potential energy, give some examples of activities that involve elasticity potential energy and take notes in their workbooks. The following points should be explained if they were not raised by the students:	**Explanation** 1. Asks some groups to explain their results in front of class. The following may be used as guiding questions: 1.1 When more force is exerted, what will happen to the spring? 1.2 What shape is the graph between force and distance? 1.3 In the graph, when the stretched distance is zero, how much force is exerted? 1.4 When stretched distance is x, how much is the force exerted?

- The stretched distance varies by the force use to stretch the spring. - The slope of the graph is the spring constant - The area under the graph between the amount of force exerted and the stretched distance equals to the work use in stretching the spring and equals the elasticity potential energy of spring  $F \quad \alpha \quad x$ F = kx $W = \frac{1}{2}kx^2$ $E_p = \frac{1}{2}kx^2$	2. Teacher further explains that the force acting on the spring is directly proportional to the displacement, or $F \quad \alpha \quad x$ F = kx (1)  3. Because the force is not constant, but increases at a constant rate from 0 to F, the work that is exerted equals the average force in the stretched distance x, or $W = \left(\frac{F_1 + F_2}{2}\right)x = \left(\frac{0 + F}{2}\right)x = \frac{1}{2}Fx$ (2) Replace F from equation (1); so $W = \frac{1}{2}kx^2$ (3) This work transfer to be an elasticity potential energy in the spring

	So $E_p = \frac{1}{2}kx^2$ (4)
Elaboration Teacher writes a problem on the blackboard Exampled 1 : If a spring has spring constant k = 150 N/m. Please find 1 the force that stretches the spring until the distance is 0.25 m 2 the elasticity potential energy when the stretched distance is 0.25 m Guiding questions for solving the first part of the problem a) What is the problem? What is the amount of force exerted when the distance is 0.25 m? b) Analyse the problem. What do we know now and what do we want to know? k =150 N/m ; x = 0.25 m; F=? c) Which heuristic is appropriate? Use equation F = kx d) Examine the result F = kx = (150)(0.25)	**Elaboration** The same as the guided inquiry approach.

= 37.5 N Guiding questions for solving the second part of the problem what is the problem? a) What is the amount of elasticity potential energy when the distance is 0.25 m? b) Analyse the problem. What do we know now and what do we want to know? k =150 N/m ; x = 0.25 m; Ep=? c) Which heuristic is appropriate? Use equation $E_p = \frac{1}{2}kx^2$ d) Examine the result E_p = (1/2)(150)(0.25)(0.25) = 4.6875 N	
Evaluation 1. Observe the students while they are discussing, answering questions, and doing the experiment	**Evaluation** The same as guided inquiry approach

Appendix 2. Excerpt from the Grade 7 science textbook (translated from Thai)

1.1 Motion of Objects

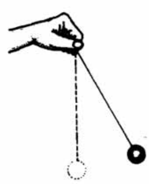
The motion of objects is part of our daily life. When moving from one place to another, we can walk, run, or travel by car. When travelling by car, sometimes we move along a straight line and sometimes we move along a curve. Besides these two types of motion, are there any other types of motion? To understand the various types of motion, try the following activity described below.

From the experiment, we found that a ball will fall in a straight line, while a sheet of paper will float and move from side to side. When a ball is thrown horizontally, it will move along a curve and fall to the ground. But when the ball is thrown vertically, it will move upwards and then downwards in a straight line. Moreover, if you throw the same ball vertically upwards with more force, it will travel further away from the ground. When you rotate a ball attached to a string, the ball will move in a circle, with the length of yarn from the ball to hand corresponding to the radius of a circle. When you swing a ball in a similar fashion as in the figure above, the ball will move forward and backward, following the arc of a circle. The length of yarn from the ball to the hand corresponds to the radius of a circle.

Objects around us move in many different ways. Fruits falling from a tree move in a straight line or have a linear motion. When a ball is thrown out horizontally, it moves along a curve or has a curve motion. A curve motion also happens when you throw a basketball in the hoop. When you sit on a playground swing, you will move back and forth following the arc of a circle. These examples show that many moving objects follow either a linear or a curved path.

Activity 1.1 : Motion of Objects

1. Take two sheets of paper of the same size and make a ball out of one of the sheets.
2. Release the paper sheet and the paper ball at the same time from approximately 1.5 meters above the floor. Observe and record the motion of both the paper sheet and the paper ball.
3. Use a rubber or any other type of ball and throw it in various directions. Observe and record the motion of the ball every time you throw the paper ball.
4. Attach a hard rubber ball to one end of a yarn of about 1 meter long. Hold the other end of the yarn and rotate the ball. Observe and record the motion of the ball.
5. While holding one end of the yarn, swing the ball back and forth as shown in the figure below.



Answer the following questions:

How did the sheets of paper and the ball move?

Did they move differently?