Assessing students' reflective responses to chemistry-related learning tasks*

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Abstract: Key to renewed concern on the affective domain of education (Fensham, 2007) and on school graduates' readiness for a world of work (DEST, 2008; WDA, 2006) is the student's inclination-to-reflect when engaged in a learning or problem-solving task. Reflective learning is not new to education (Dewey, 1933; Ellis, 2001). Since the inclination-to-reflect may not be obvious even among adults at work (Seibert & Daudelin, 1999), how much more can we expect from school students? This article presents part of a research on secondary school students' inclination-to-reflect when engaged in chemistry learning tasks. The instrument used is the three-part Chemistry Learning and Thinking Instrument (CLTI). The first part seeks to characterize students' inclination-to-reflect while attempting chemistry learning tasks and the other parts aim to characterize their learning-thinking preferences in the subject. This article shares the construction of the learning tasks in the first part and how students' reflective responses to these tasks are encouraged, scored and analyzed. Since assessment is said to drive teaching and learning, an alternative form of assessment, such as these CLTI items, may help students become more reflective in their learning habits and hence more adaptable to the world of work.

Key words: affective science education; Chemistry Learning and Thinking Instrument (CLTI); inclination-to-reflect; reflective learning

1. Introduction

Renewed concerns on the affective domain of education (Fensham, 2007) and on school graduates' readiness to enter the world of work (Department of Education, Employment and Workplace Relations, DEST, 2008; Work Development Authority, WDA, 2006) point to an important development in the way students are being prepared in school—their approaches to solving problems. Being reflective is a well-known thinking habit among scientists. Good examples include renowned scientists like Isaac Newton (1643-1727, discoverer of gravity), Gregor Mendel (1822-1884, the father of hereditary science) and August Kekulé (1829-1896, who first proposed the molecular structure of benzene in 1865). Being reflective is also encouraged and recognised as an essential habit among good problem solvers (Stroulia & Goel, 1994) and in everyday life (Brockbank, McGill & Beech, 2002; Covey, 1989; Harrison, 2006). Since assessment is often said to drive learning habits (Enger & Yager, 2001; Gronlund & Waugh, 2008), it may therefore be useful to consider assessing students' inclination-to-reflect so that students can be encouraged to become habitual reflective learners. Hopefully, this will also better prepare them for a more

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complex and demanding world of work.

This article presents a part of a research on secondary school students’ inclination-to-reflect while engaged in Chemistry learning tasks. The instrument used is the three-part Chemistry Learning and Thinking Instrument, or CLTI. The first part seeks to characterize students’ inclination-to-reflect while attempting Chemistry learning tasks and the other two parts aim to characterize their learning-thinking preferences in the subject. Only the first part of the CLTI will be discussed, including how students’ reflective responses to the learning tasks are scored and compared. The purpose is not to report in detail the findings of the research but to share an alternative way to assess students’ ability to solve problems or respond to learning tasks in school chemistry.

2. Defining reflective learning

The reflective approach to learning is not a new idea in education. Among the earliest recorded works relating to reflective learning are those of Socrates (the great 5th Century B.C. Greek philosopher). Socrates once said, “The unexamined life is not worth living” (Brickhouse & Smith, 1996, p. 209). Though this may sound harsh, it is undeniable that the human race would not have made the progress we see now if people had not been observant of their surrounding, asked the appropriate questions and generated possibilities to work on so that our lives can be more comfortable. In 1933, renowned educationist, John Dewey had written about reflective thinking and the education of man. Dewey’s work suggested that to understand life experiences better, we can “… take stock of the conditions before suggestions arise of possible course of action” (Dewey, 1933, pp. 102-103). This involves the learner taking time to pause and look into the future, recapturing past experiences and establishing a relationship between these experiences and thoughts on a new basis. The experiential learning cycle was then proposed by Kolb (1984) as a model of learning with reflection as a key element. Kolb’s model explained how reflecting on experiences helps to further develop the person’s learning capacity.

The literature may be extensive and reaches far back in history but few are empirical studies about the intervening applications of reflective learning strategies. Most of the reported work deal with adult learning and professional practices (Branch & Paranjape, 2002; Loughran, 1996; Moon, 2004; Pollard, 2002; Schön, 1983, 1987; Seibert & Daudeline, 1999; Tan & Ee, 2004; Taylor, 2006). Those that relate to younger learners and school students appear to be reports on best practices or sharing of a variety of learning-teaching strategies (Trudeau & Harle, 2006; Wilson & Jan, 1993). However, in almost all reports two important precursors to reflection—time and experience, were frequently reported. Reflective learning may then be defined or described as a form of learning that requires the learner to pause and observe her or his learning situation by considering past relevant experiences and using these to generate useful information from the present situation. The learner can then make sense of the learning process by linking the past, the present and/or the future.

3. Applying reflective learning

Many reflective learning strategies have been suggested or described as applicable in a classroom or science laboratory setting (Ellis, 2001; Fogarty, 1994; Tan, 2002, 2005, 2007; Whitaker, 1995; Wilson & Jan, 1993). Practising classroom teachers are probably familiar with procedural strategies like: (1) KWL, which is commonly used in a lesson to identify “what I Know, Want of know and what I have Learnt”; (2) Question authoring, like the use of "What if …" questions, during a lesson or project involving critical thinking and problem solving (Channel News Network, CNN, 2003; Fogarty, 1994; Tan, 2007), and review procedures like (3) Establishing clear-unclear windows (Ellis, 2001; Fogarty, 1994), which may include activities like concept mapping and learning logs written as a form of self-evaluation before, during and after a lesson. These strategies require learners to reflect. Many similar strategies are also applicable in experimental science or laboratory practical activities. For example, inquiry-related strategies like (1) POE (Predict-Observe-Explain) are commonly used before or during an experimental lesson and (2) recovery strategies (Ellis, 2001; Fogarty, 1994), for trouble-shooting during problem solving in a practical session. Since teachers are already employing some forms of reflective learning strategies in their lessons, it is therefore reasonable to state that reflective learning is not a new idea in education.

Reflective learning strategies are also metacognitive in nature (Fogarty, 1994), that is, students are encouraged to think about their thinking (Flavell, 1976, 1979). Exposing them to such learning strategies may develop them into metacognitive and reflective learners. Being reflective means the learner not only has to think about her or his own learning-thinking approaches (metacognitive) but also to make sense of what they have done, are doing and will proceed to do. In other words, they become actively engaged in what Schön (1983) called in his book, *The Reflective Practitioner*, "reflection-in-action" (reflection while the event is still going on) and "reflection-on-action" (reflection at the end of an event).

Although it appears simple to describe reflection as a learning habit or strategy, it may not be as easy to conclude if someone is reflecting or not. Reflecting as a human activity is a form of thinking that that cannot be visibly observed. Nobody can observe another person's thinking process visually. The same may be said of reflection. It is therefore necessary to provide "proxies" to indicate that a learner is, or has indeed been, reflecting and not daydreaming or pretending to think. Hence, the survey instrument used in the present research provides opportunities to collect some concrete evidences on student's reflection.

4. Students' inclination-to-reflect in learning school chemistry

Based on the reflection literature, a model was established by Tan and Goh (2002) to explain how reflective learning could take place in the classroom. A strategy that may be applied in the classroom learning situation comprises three skills commonly illustrated in most reflective learning activities. These are namely, observe, generate and relate (Figure 1). The reflective learning model and strategy were further developed by Tan (2008) to include the roles of reflective teaching in a classroom lesson (Figure 2). This model was then used in the construction of an instrument to characterize the reflective learning-thinking approaches of secondary three Chemistry students in Singapore. The instrument, known as the Chemistry Learning and Thinking Instrument (or CLTI), includes a list of ten chemistry-related learning tasks. Students' scores on these tasks were compared to the sample's mean and used to place each student in the "high" group (more "inclined-to-reflect" compared to the sample's mean performance) or the "low" group (less "inclined-to-reflect").

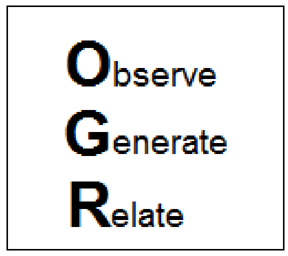


Figure 1 The OGR reflective learning strategy in the classroom

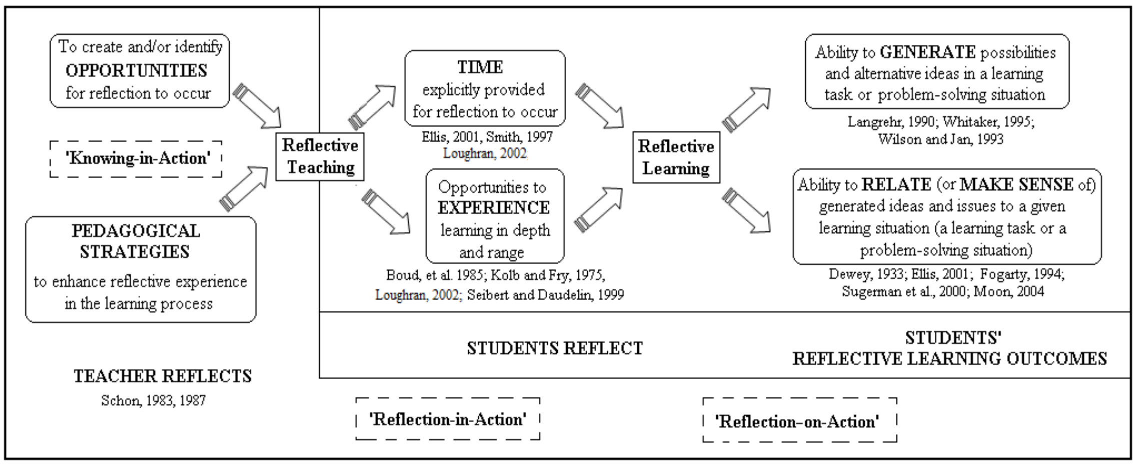


Figure 2 Model to explain reflective teaching and reflective learning in the classroom (Tan, 2008)

The CLTI is not a psychometric instrument used for measuring the degree of reflectiveness in learning. Instead, it is used to characterize students' learning-thinking approaches. The items serve to engage students in generating alternative and meaningful solutions or responses to the Chemistry learning tasks. Students are required to respond to all items by writing down their answers in the spaces provided. There are no structured prompts to help students respond. That is, no boxes or brackets for ticking and no lines are provided for writing because students may take these as indications of how many possible answers or alternatives they can generate. They are only told to write their responses in the blank spaces provided. All questions (with a few exceptions) carry the general instruction to "list all possible answers or alternative solutions" to the task. This is to engage the more reflective students to take time to think and link their own experiences with the learning tasks and generate more relevant alternatives or possible solutions. A two-tier scoring scheme is then used to evaluate the students' responses (Table 1).

Table 1 Two-tier scoring scheme for students' responses to the items in the CLTI

Tier	If the student is to make a	Score
1	*relevant* or *related* response	one point
2	*correct* or *accurate* response	a maximum of two points

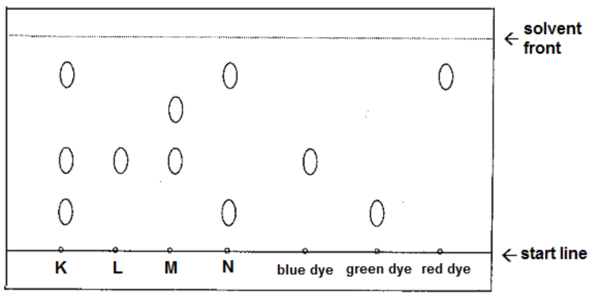
A relevant or related response may be completely or partially correct. A correct or accurate response[1] refers to a conceptually correct response to the learning task. The total number of relevant or related responses will then become the student's first tier score. The scorer will then re-visit the list of responses, evaluates the correctness or

[1] All items and responses are subjected to vetting by a panel of experts. The inter-scorer consistency for the items was at 0.75.

accuracy of each response and awards the student the second tier scores for the same responses. The overall performance for that student on a particular learning task will be the sum of the two scores. Thus, the higher the student's overall score, the more inclined she or he is to reflect.

As an example of how a student's response was scored, consider a student who had listed three correct alternatives or possibilities. She or he would have scored [(3x1)+(3x2)], that is 9 points. If out of the three responses related to the task, only two were correct and the remaining was either incorrect or inaccurate, then she or he would have scored [(3x1)+(2x2)+(1x0)], that is 7 points. Similarly, if all three responses were incorrect but relevant to the theme of the task, then the score would be [(3x1)+(3x0)], that is 3 points. Figure 3 shows at typical CLTI item and Figure 4 presents examples of some actual students' responses for this item.

The following diagram shows a chromatogram obtained using solutions of three single dyes (blue, green and red) and four other solutions (K, L, M and N) that contain one or more dyes.



List all the possible conclusions that can be made from observing the chromatogram obtained above.

Figure 3 Sample item of the CLTI (Topic on chromatography, Item B9)

Example A: All generated conclusions are relevant, correct and accurate (Respondent MD025).

K is a mixture of green dye, blue, dye and red dye.
L is a pure dye containg only blue dye.
M is a mixture containing blue dye and a unknown dye.
N is a mixture, containg red dye and green dye.

Scoring: All four points are relevant and correct. Hence the score for this response is [(4 x 1) + (4 x 2)] = 12 points.

Example B: Same task but with one incorrect conclusion (Respondent MD010).

K is made up of red dye and two untnown dyes
L is made up of blue dye
M is made up of blue dye and an unknown dye.
N is made up of green dye and red dye.
Red dye is the most soluble followed by the blue dye and green dye

Scoring: All five conclusions are relevant, but only the first conclusion is incorrect. Hence the score for this response is [(5 x 1) + (4 x 2) + (1 x 0)] = 13 points.

(continued)

Example C: Partially correct conclusions (Respondent HB003).

K contains dyes of green, blue and red.
L contains ~~dye of blue~~ blue dye.
M contains blue and an unknown dye.
N contains green and red dye.
Both ~~a~~ M and N contains red dye.
K, L and M contains blue dye.
Both K and N contains green dye.
M and N contains two dyes.

Scoring: All eight conclusions are relevant to the task requirement but the fifth conclusion is partially correct (M does not contain the red dye). The sixth and seventh points are repeats of observations made in the earlier points but these are correct conclusions. On a second tier scoring, these three conclusions may be awarded one point (out of two) each. Hence the score for this response is [(8x1)+(5x2)+(3x1)]=21 points.

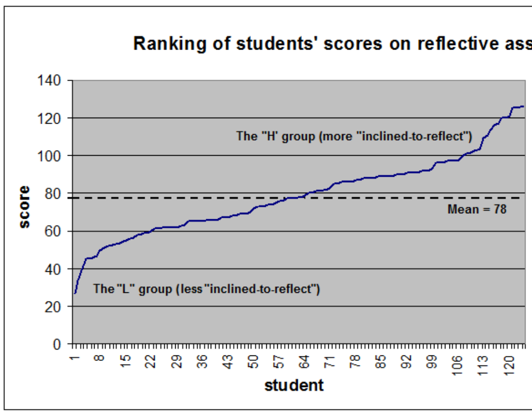
Figure 4 Examples on scoring responses to CLTI item

In example C (Figure 4), the scorer had also awarded 1 point out of 2 possible points to a partially correct or accurate response. Hence, the scoring on the second tier allows some leeway for the scorer to gauge the quality of a relevant response.

The student's total score for the ten items were then computed and compared to the mean total score of the sample. Students who scored higher than the sample's mean total score would be identified with an "H" characteristic for being more inclined-to-reflect compared to the rest. Those with a score lower than the sample's mean total score fall within the group identified with an "L" characteristic.

5. Results and findings

The CLTI was administered as part of a doctoral research on *Students' Ideas in Designing Experimental Set-Ups and their Reflective Learning-Thinking Approaches in School Chemistry* (Tan, 2008). The sample studied for this report comprises 124 secondary school chemistry students who had completed at least one year of study at upper secondary level (at the end of secondary three or early secondary four). Figure 5 shows the distribution and ranking of the students' scores for the ten-item CLTI survey.



Mean	78.27
Median	78.00
Mode	65.00
Range	105.00
Minimum	27.00
Maximum	132.00
SD	2.25

Figure 5 Distribution and ranking of students' scores for the ten-item CLTI survey

The results were used in the original study to answer the research question on whether students who are more inclined-to-reflect can design better chemistry experimental set-ups. "Good designers" in the study are those who scored consistently well in designing tasks listed in a separate four-task survey form, the Experimental Design Task List (EDT List). These "good designers" were frequently found to have higher scores on inclination-to -reflect in the CLTI survey (Tan, 2008). The group with lower scores were found to perform poorly on the EDT List. Hence, the study provided some empirical evidence to show that being reflective in their habit of learning may have helped students perform better in problem-solving tasks like designing experimental set-ups.

6. Discussion and recommendations

The main research using the survey instruments (CLTI and EDT List) has yielded some useful findings, including evidences that "good designers" of experimental set-ups are more inclined-to-reflect compared to the "poorer designers". The more reflective students could have been more observant and thus identified more possibilities or alternatives. These could have helped them design more appropriate set-ups for the experimental design tasks presented in the survey.

Two of the several recommendations made in the study are: (1) to re-word assessment tasks commonly found in most examination papers in an open-ended manner in order to encourage reflective responses from students, and (2) to assess students periodically using reflective assessment items (like those in the CLTI). Using the two-tier mark scheme, or similarly crafted mark schemes, it is possible to grade students over a range of scores, with the higher scores being indicative of students' greater inclination-to-reflect. Students may become habitual reflective learners if they realize that being reflective in their learning approaches can help them solve problems more effectively.

There are limitations to a reflective mode of assessment, like:

(1) A large amount of time has to be spent crafting reflective assessment items or re-crafting from typical assessment items, and in scoring students' reflective responses;

(2) Ambiguities in students' reflective responses, since these assessment items are open-ended and there can be a host of possible responses and;

(3) The readiness of teachers to embrace unfamiliar situations posed by the open-ended nature of the reflective assessment items and the less predictable responses from their students.

The limitations are important and should therefore be carefully considered in future efforts relating to assessment of students based on their inclination-to-reflect. One strategy to tackle the problem of having to spend a lot of time in teaching and preparing students to respond to reflective assessment items is to frequently expose students to short reflective learning exercises. Also, including one or two reflective assessment items in a typical examination could encourage students to adopt a more reflective approach to their learning. Ambiguities surrounding some of the students' responses may also be dealt with during professional discussions and documented by teachers and examiners so that experiences learnt may be used to craft similar items in future assessment. The research also found that establishing an inter-scorer consistency among randomly selected items helped make the reflective assessment items more reliable. Finally, teachers preparing students for reflective assessment need to be proficient both in content knowledge and in pedagogical skills. Continual professional development for teachers in guiding students towards a more reflective mode of learning in class is therefore recommended.

7. Conclusion

Research on developing objective ways to measure reflectiveness in learning had previously led to critical discussions (Kagan, 1965; Krumboltz, 1965). Despite the lack of empirical studies on reflective learning, especially within the school context, it is obvious that measuring reflectiveness in learning can be difficult, if not impossible. For example, it can be doubtful to suggest that learner A is twice or three times more reflective than learner B. The scores and analyses from the CLTI only serve to describe students as being more or less inclined-to-reflect when compared to the sample's mean. Although this may appear to be a straightforward research strategy, it is probably a first step towards assessing students on their ability to solve problems through a reflective approach. This different mode of assessment may help students change their strategy in preparing for assessment. Instead of blindly practising to solve problems and mugging to remember facts so as to achieve high test scores, they may now strive to generate alternative relevant ideas to a learning task or problem, thus engaging them to reflect critically and frequently. Despite the limitations and apparent straightforwardness in the conduct of the study, the results do hold some promises that a more objective way to assess students' reflective responses may become part of typical school examinations in future. It will be worth the time and effort to conduct a reflective mode of assessment since it can increase the chances of nurturing the younger generation of learners to become more reflective. In a fast-paced world fuelled by an expanding knowledge base and supported by highly technology-dependent systems, being less impulsive and making informed decisions may be critical soft skills students will need now and in the near future. To help students acquire such skills, one way forward is to encourage reflective learning in schools.

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