THE EFFECT OF INTENTIONAL CRITICAL THINKING INSTRUCTION ON IT LEARNERS' SELF-DIRECTED LEARNING

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ABSTRACT – In the South African Information Technology (IT) curriculum (Grades 10-12), software development makes up 60% of the curriculum, however it is often reported as being the most difficult. Critical thinking (CT) is needed to be successful with computer programming. The aim of this research therefore was to determine the effect of intentional CT instruction (CTI) on Grade 10 IT learners' Self-Directed Learning (SDL) and CT. We implemented intentional CTI in some Grade 10 IT classes and intentional CTI was infused into pair programming (PP) into other IT classes. We conducted a QUANT-qual mixed-methods investigation where the quantitative investigation was informed by a quasi-experimental design and the qualitative investigation was informed by an interpretivist design. Using the Cornell CT Test-Level X and the SDL Instrument we could quantitatively measure the learners' CT and SDL. To further understand learners' disposition toward the CTI, narrative questions were given to learners as part of the post-test investigation. From our investigation, we found that IT learners' CT skills as well as SDL had decreased after implementing the CTI. In this paper we conclude that intentional CTI, at least over a short period of time, does not hold the key to increase IT learners' SDL, nor does it lead to enhancement of their CT. This finding is counter-intuitive; therefore we present several reasons as to why these IT learners' CT would decrease after intentional CTI, with or without PP.

Keywords: Critical thinking; Self-Directed Learning; Information Technology; Computer Science Education; Pair programming.

1. INTRODUCTION

Self-Directed Learning (SDL) is a process in which an individual takes responsibility for their own learning by taking initiative in diagnosing learning needs, formulating learning goals, identifying human and material resources needed for learning, choosing and implementing appropriate learning styles and evaluating the learning outcomes (Knowles, 1975:18). Critical Thinking (CT) is described as "a purposeful, self-regulatory judgment that results in interpretation, analysis, evaluation, and inference, as well as explanation of the evidential, conceptual, methodological, criteriological, or contextual consideration upon which that judgment is based" (Facione, 1990:2). Although CT is one of the skills emphasized in education, especially in technical subjects like Information Technology (IT) where learners need to be able to critically reflect about decisions and implement problem solving. Goede and Taylor (2011) found that learners do not possess it after completing their formal schooling. Apart from CT playing an important role in IT, SDL is also needed. In the Curriculum and Assessment Policy Statement (CAPS) for IT, it is stated that software development (programming) weighs most, at 60% of the subject content to be mastered (Department of Basic Education, 2012). Without the ability to be self-directed, learners will experience difficulty keeping up with rapid-changes occurring in the subject. To address the challenges faced in programming (where CT is required) and keeping up with the constant changes (where SDL is required), SDL and CT development is needed; therefore the question that guided the research was: What effect does intentional CT instruction (CTI) have on Grade 10 IT learners' SDL and CT?

2. CONCEPTUAL AND THEORETICAL FRAMEWORK

The three main concepts that guided this investigation were: SDL, CT and cooperative learning (CL). The conceptual and theoretical framework that emanated from merging these three concepts was the socio-cognitive theory. This framework will be discussed subsequently.

2.1. Self-Directed Learning

The most commonly used definition of SDL is that of Knowles (1975:18). Gibbons (2002), however, notes that six skills are needed for SDL: ask questions, find relevant information, analyze a situation, make thoughtful decisions, determine an own point of view (based on judgment) and test if the point of view/judgment is correct. In addition, Long et al. (2000) noted seven tasks for which learners are responsible in an SDL setting: understand the coursework, attend classes, actively participate in lectures, execute assignments, be prepared for class, engage in small group discussions and participate in the field of study. Silén and Uhlin (2008) and Guglielmino (2013) also state that group work promotes SDL. Apart from SDL being a valuable general skill, it is also important in computing fields (Goede & Taylor, 2011).

According to Zander et al. (2012), it is universally accepted that technical fields that possess constant change require professionals to keep learning throughout their careers. SDL in computer programming was studied by Boyer, Langevin and Gaspar (2008) who found that by making use of specific teaching activities (peer learning, forums and 'live coding hands-on exercises'), students' self-direction improved. Goede and Taylor (2011) also note that SDL of Information systems students need to be developed in order to prepare them for lifelong learning in the computer science profession.

Grow (1991) notes that SDL development is possible; however it is a gradual process. Douglas and Morris's (2014) study revealed three factors influencing students' development of SDL: student-controlled elements, faculty-controlled elements and administration-controlled elements. Apart from these factors, Straka (2000) emphasizes factors that occur outside the classroom, such as cultural influences and socio-historical influences. These factors call for a fourth category to be added to Douglas and Morris's elements which can be termed 'inexplicitly controlled elements'. All four elements are important to foster the development of SDL in Computer Science Education (especially in the context of IT at school level). These four elements are closely related to social and cognitive skills such as communication and other social skills, whilst higher order thinking skills constantly inform the factors conducive to students' development of SDL.

2.2. Critical thinking

CT is one of the oldest approaches to thinking, dating back to the times of philosophers like Socrates (the father of CT) and Aristotle (Alazzi, 2008). CT emanates from John Dewey's reflective thinking and it was Dewey himself that coined the term CT (Dewey, 1922). Several definitions could be found in the body of scholarship on CT (Halpern, 2003; Facione, 1990). Facione's definition of CT (as described earlier) was accepted in this investigation. It is important to take note that CT does not only include cognitive and metacognitive skills but also self-regulation, a necessary ability for a self-directed learner (Long, 1988). As with SDL, CT is also important in Computer Science Education.

Fuller et al. (2007) argue that the essence of computer science is problem identification and finding the most effective and efficient way to solve it. This relates to CT as described by Sosu (2013) in that CT focuses on the individual's ability to identify a problem and give a reasonable solution for the problem. CT also assists in the success of computer programming; therefore teachers need to shift the focus of their classes from requiring the mere memorization of programming syntax to the facilitation of the development of skills that are conducive to successful programming. Fagin, Harper, Baird, Hadfield and Sward (2006) state that when assisting learners with the development of CT skills, computer programming skills increased significantly. When referring to the definition of CT (Facione, 1990), we see that the skills needed for programming (willingness to persist, problem-solving skills and creative

skills (Fincher, 2006)) are all encompassed in the definition. Since CT is important, the development of CT needs elucidation.

Fisher (2005) notes that an individual's development of CT should be fostered explicitly as its development does not necessarily occur naturally. Halpern (2003) and Dunn, Halonen and Smith (2008) claim there is evidence that CT can be developed, although it is hard to do so. Certain factors, however, need to be taken into account when attempting to foster learners' CT.

Cultural influences on CT have been noted as minor (Manalo, Kusumi, Koyasu, Michita & Tanaka, 2013). It has also been reported that CT skills are not influenced by intellect or gender (Myers & Dyer, 2004). Halpern and Marin (2011) focused on determining whether CT was better taught explicitly or imbedded, and found that both of the groups' CT skills improved; however, the explicit instruction group scored much higher than the imbedded group, implying that an intervention targeting specific CT skills is a viable option.

From the two points discussed above, it is evident that the development of CT through explicit instruction is beneficial. Van Gelder (2001) and Snyder, and Snyder (2008), are of the opinion that CT is most effectively developed when the facilitator exhibits CT skills. Dunn et al. (2008) note that teachers should model effective CT skills in class and share experiences where they have implemented CT in everyday life. There are several strategies that can be used to model CT in the classroom. Apart from the modeling techniques described by Brookfield (2012), certain teaching-learning strategies are also conducive to CT development. Snyder and Snyder (2008) emphasize the importance of actively engaging students in the learning process. Examples of active learning include the Socratic Method and CL.

Schiller (2008) describes the Socratic Method as a pedagogical method that pursues the truth by means of analytical discussion. Carvalho-Grevious (2013) found that by using the Socratic Method, students' CT was enhanced and students enjoyed the opportunity of being engaged in the CTI and its assessment. Boghassian (2006) also promotes the use of discussion to develop CT. Another instructional method that advances the use of discussion is CL.

Researchers like Moss (2004) found that through discussion in a CL environment middle school learners' CT is fostered. As CL holds benefits for CT and SDL development, it will be discussed below.

2.3. Cooperative learning

Johnson and Johnson (2014) describe CL as the use of small groups when students work together to maximize not only their own learning but also the learning of others and that there are five basic elements to be adhered to for successful CL: (i) Positive interdependence – when the individuals in the group realize that they are going to sink or swim together because the group's success also reflects the individual's success (Johnson & Johnson, 2014); (ii) individual accountability – when the individual realizes that they have an individual responsibility towards the group and that they will be held accountable as an individual in the group (Johnson & Johnson, 2014); (iii) promotive face-to-face interaction – when group members assist one another by providing guidance and resources as well as challenging each other's reasoning and judgments (Johnson & Johnson, 2014); (iv) appropriate use of social skills – an attempt to assist group members in the acquisition of social skills (communication skills, praising skills, supporting skills, etc.) in order to contribute to the success of the group (Johnson & Johnson, 2014); (v) group processing – the metacognitive factor in the group work process when the group has the opportunity to assess and evaluate their progress, strengths and weaknesses and identify aspects which could have been done better or were executed well (Johnson & Johnson, 2014).

One possible implementation of CL in the IT class is that of pair programming (PP) (Mentz, Van der Walt & Goosen, 2008). Mentz et al. (2008) describes PP as a strategy where two learners - one having the

role of the driver and one having the role of the navigator - work side by side on one computer to solve a problem.

The preceding discussion was focused on CT, SDL and CL. CT is an important concept in education and in IT specifically as CT promotes successful computer programming (Fagin et al., 2006). SDL is a cognitive educational goal necessary for increased success in any field of study, but especially in the rapidly ever-changing field of technology, acquired through social interaction. Closely related to the success of SDL is CT (also of importance in the rapidly ever-changing field of technology). CL is conducive to both CT and SDL development as learners have the opportunity to argue with one another and learn to take individual responsibility for learning (enforced by the positive interdependence and individual accountability). In the light of the fact that these concepts all emphasize cognitive and social skills as important building blocks, it is viable to position the three concepts within a SCT of learning. SCT can be defined as a social approach that extends beyond the social learning theory in that it "acknowledges the joint roles of cognitive factors, self-beliefs, and environmental factors in human learning" (Winne & Hadwin, 2011:34). From a SCT perspective, learning occurs in interaction between the individual and the social environment (Bandura, 1977; Vygotsky, 1978). Learning, in this study, is therefore seen as a social and collaborative activity in which people develop their thinking together (James, 2006). SCT can be seen as the crystallization of the three concepts. With the conceptual-theoretical framework discussed, the following section focuses on the research methodology.

3. EMPIRICAL INVESTIGATION

3.1. Research design

Within the pragmatist paradigm - focusing on 'what works' (Creswell, 2009) - we conducted a QUANT-qual mixed-methods investigation where the quantitative investigation was informed by a quasi-experimental design and the qualitative investigation was informed by an interpretivist design.

3.2. Research aim

We wished to determine whether intentional CTI "worked" to enhance students' SDL and CT.

3.3. Research strategy and ethical considerations

We implemented Brookfield's strategies for modeling CT ('speaking in tongues', compiling an 'assumptions inventory', engaging in structured devil's advocacy and ending lectures with discussions and questions) and the Socratic method (both to deliberately develop CT); PP was implemented as a CL strategy. By implementing deliberate CTI individually as well as infused into PP, we aimed to investigate its effect on IT learners' CT and SDL. The investigation was informed by the North-West University's research ethics code.

3.4. Population and sampling

High schools from three provinces (North West, Free State and Eastern Cape) in South Africa (offering IT as an elective) were selected. The investigation was informed by a quasi-experimental design; therefore schools in these provinces were randomly assigned to one of two groups: Group 1 (only intentional CTI intervention) and Group 2 (CTI infused into PP intervention). From the schools included in the investigation, Grade 10 IT learners and teachers were asked to participate. Six schools (58 learners) were selected for the CTI only and 4 schools (87 learners) for the CTI infused into PP invention.

3.5. Intervention

Two interventions took place: The CTI intervention required IT teachers to implement deliberate CTI in their classes for approximately six weeks; the CTI+PP intervention required IT teachers to implement PP in their classes, but to also infuse the CTI into the PP. All teachers were supported by means of one-on-

one face-to-face professional development where one of the researchers communicated the possible strategies that could be implemented in the IT class. Teachers received a manual and learning support material (keyring and videos) to guide IT learners through the strategies.

3.6. Data collection

Data collection was done by distributing measuring instruments, the Cornell CT test-Level X (CCTT) and the SDL Instrument (SDLI) by Cheng, Kuo, Lin and Lee-Hsieh (2010) at the beginning of the empirical study. After the intervention, the same measuring instruments were again used. Learners were asked to complete a narrative on whether they felt their CT skills had improved and how they had experienced the suggested strategies. IT teachers also participated in semi-structured interviews at the onset of the study and again at the end to determine their experiences of the strategies.

3.7. Validity, reliability and trustworthiness

A pilot study to determine the validity and reliability of both measuring instruments in the South African context at high school level was conducted. Reliability was determined by calculating the Cronbach's alpha coefficient for each construct in the CCTT (ranging from 0.5 to 0.8) and the SDLI (ranging from 0.5 to 0.7). A peer-debriefer was appointed to increase trustworthiness in the qualitative investigation.

3.8. Data analysis

The empirical data gathered with the use of the CCTT as well as the SDLI were captured electronically. The Statistical Consultation Services of NWU (Potchefstroom Campus) executed the statistical analysis. Descriptive statistics were done in order to determine, amongst others, the standard deviations (SD) and mean scores. The fact that predictor variables occur at different hierarchies called for the use of Hierarchical linear models (Hancock & Mueller, 2010), taking into account the interrelationship of learners in a class, to determine the p-value and d-value. Coding of transcripts was done by making use of the ATLAS.ti to keep track of how codes were defined. Descriptions of findings were given by making use of concise descriptive discussion.

4. RESULTS

Table 1 illustrates the difference between the pre- and the post-test for the SDLI per school. As some learners seemed to have rushed through the questionnaires, only learners who completed both the questionnaires in more than 45 minutes were included in this investigation.

Table 1: Self-Directed Learning Instrument results

Group	School code	N	Pre/Post	Mean	SD	p	d
Group 1	1	3	Pre	72.33	3.21	1.000	0.00
			Post	72.33	16.26		
	2	4	Pre	81.00	11.75	0.144	**0.61
			Post	73.85	8.00		
	11	5	Pre	75.84	9.55	0.176	*0.46
			Post	71.40	12.78		
	21	3	Pre	68.67	5.86	0.383	*0.23
			Post	67.33	7.02		
Group 2	4	8	Pre	81.73	8.56	0.111	*0.40
			Post	78.33	9.63		
	6	24	Pre	85.34	7.61	0.497	0.11
			Post	84.50	8.10		
	15	3	Pre	77.00	13.75	0.150	*0.39
			Post	71.67	11.02		

* small effect
** medium effect

When looking at Group 1 and Group 2 (see Table 1) none of the schools showed any increase in SDL. In fact, learners' SDL in both groups decreased (in some cases with a small to medium practical significant difference).

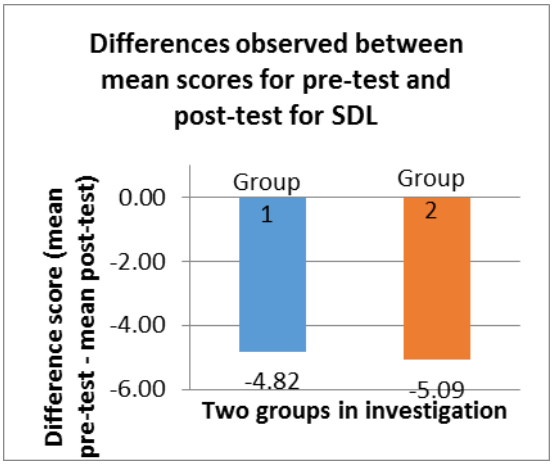

Figure 1: Mean score differences between pre-test and post-test for Group 1 and Group 2: SDL

Figure 1 illustrates that there was a larger decrease between the pre- and post-test mean scores for SDL in Group 2 than in Group 1. The qualitative findings from IT learners and teachers pertaining to SDL in the IT classrooms are subsequently discussed.

Group 1

SDL aspects that were evident from the qualitative findings of both IT learners and IT teachers in Group 1 illustrated that SDL was evident in these IT classes: (i) IT class increases sense of self (confidence): *"And they don't feel so daunted anymore" (Teacher);* (ii) IT class creates a platform for cognition/metacognition: *"We questioned the question (asked questions about the question) and once we got answers, answering the question was easy and fun" (Learner)*; (iii) IT class addresses use of resources and development of life skills; and (iv) the IT class stimulates learning flexibility. Although similar aspects regarding SDL were evident from both learners and teachers, it is disconcerting that the CTI intervention did not yield many more aspects of SDL.

Group 2

From the two groups in this research, Group 2 also noted SDL aspects. Although the same categories were visible for teachers and learners (as in the other group), the number of codes and quotes

(references made by participants to SDL) were higher. One of the teachers noted that through the use of pair programming, learners were held more accountable and therefore CTI+PP (according to this teacher) (i) increased learners' sense of responsibility. From one of the learners it became clear that their CTI+PP class had (ii) created a platform for cognition/metacognition through the focus of evaluation: *"It [the CTI+PP intervention] has taught me to evaluate and answer questions easier" (Learner).* Probably the most exciting SDL aspect noted by one of the teachers in this group was the (iii) learning flexibility shown by learners in the sense that learners learnt to work in pairs but also have the ability to work individually: *"So at the end of the day both walk out having learned something…" (Teacher).*

It becomes clear from the qualitative findings reported that SDL is evident in these IT classrooms; however we note that it seems probable that Group 2 shows more application of SDL when compared to Group 1. Table 2 illustrates the CCTT pre-test and post-test results for the two groups.

Table 2: Cornell critical thinking test–Level X results

Group	School code	N	Pre/Post	Mean	SD	p	d
Group 1	1	3	Pre	41.67	6.11	0.535	**0.54
			Post	38.67	5.51		
	2	4	Pre	36.50	6.25	0.769	0.15
			Post	37.50	6.76		
	11	5	Pre	36.40	1.00	0.891	*0.29
			Post	36.00	2.07		
	21	3	Pre	46.00	6.25	0.034	***0.99
			Post	50.67	4.73		
Group 2	4	8	Pre	26.63	5.63	0.015	*0.41
			Post	29.13	6.06		
	6	24	Pre	27.54	5.66	0.543	0.15
			Post	28.42	5.82		
	15	3	Pre	40.67	4.16	0.370	***0.85
			Post	35.67	5.86		

* small effect

** medium effect

*** large effect

When looking at CT (see Table 2) only one of the four schools in Group 1 showed an increase between the pre- and the post-test with a practical significant difference. Comparing the pre- and post-test of Group 2, only one of the three schools showed an increase in CT with a small practical significant difference. When referring to Table 2 it is clear that neither the deliberate CTI nor the CTI infused into PP significantly improved the learners' CT.

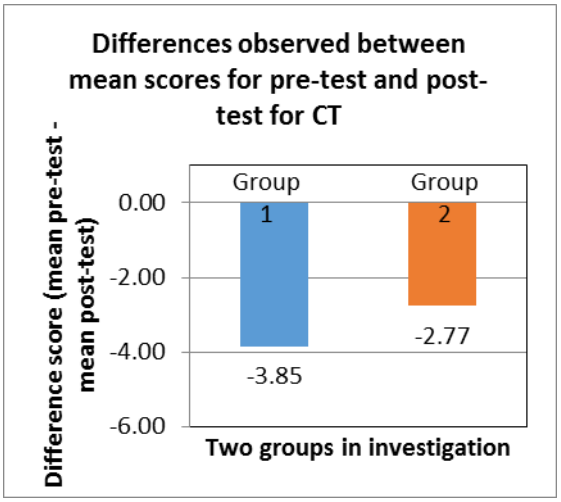

Figure 2: Mean score differences between pre-test and post-test for Group 1 and Group 2: CT

Figure 2 illustrates that there was a larger decrease between the pre- and post-test for CT in Group 1 than in Group 2, which implies that PP might have been more conducive to CT development. The qualitative findings from IT learners and teachers that pertain to CT in the IT classrooms are subsequently discussed.

Group 1

Four categories of CT emerged from the interviews and narratives: (i) focusing on problem solving: *"We were taught that before we start programming we must plan first, analyze the question critically and interpret the question in my own words" (Learner),* (ii) encouraging cognition and metacognition: *"Before every decision I make I think of the best possible solution and think of all the advantages and disadvantages" (Learner)*; *"I gave myself an opportunity to understand and learn more" (Learner); "… now I am forcing them to say before we do, let's plan and think and let's discuss it as a class or with your partner … I think on that part I have improved" (Teacher);* (iii) encouraging positive dispositions: *" It was ma'am can we do this again, I'm actually learning something" (Teacher); "I am a person who likes to know answers for the questions" (Learner);* (iv) illustrating the use of different perspectives: *"I think that speaking in tongues [is my favorite], because if I understand it correctly it is when a learner gives you an answer and you give him two alternative answers so he can choose" (Teacher).* It is clear; however that more learners made mention of CT aspects than teachers, raising cause for concern as to whether teachers were confident in their implementation of the CTI.

Group 2

IT learners in this group exhibited the most CT aspects in their narratives: (i) focusing on problem solving: *"It has helped me a lot because now I know how to make a decision regarding what action should be taken to solve the problem" (Learner)*; *"It developed me as I am looking at problems differently before solving them and gathering information before solving as well" (Learner);* (ii) encouraging cognition and metacognition: *"When faced with a new problem, I take time to weigh the pros and cons as well as try to form a structured solution for the problem, these are all thinking processes I have learnt from IT" (Learner); "It [the IT class] helped me work easier and understand things faster" (Learner);* (iii) encouraging positive dispositions: *"Then from there they were interested and they sat in pairs and from there they analyzed the CT strategy and after that it was easy for them to get through the problem" (Teacher);* (iv) illustrating the use of different perspectives: *"[I tell learners that] I will teach them to think, not only to solve problems but actually to look at it from different angles" (Teacher).* From these quotes of learners it is evident that the CTI+PP class had encouraged CT for IT learners. Although IT teachers also focused on CT aspects in their interviews, they emphasized the pair programming aspects much more than the CT aspects; furthermore it seemed evident that they were not as convinced about the CT development of the IT learners as the IT learners were.

From the qualitative results it became clear that IT learners emphasized their CT experience and development more than their IT teachers did – this could possibly be due to the fact that IT teachers were involved in interviews (may have caused some reluctance to be honest) or perhaps learners just experienced the implementation of the different strategies positively. What is probable to note is that CT aspects were evident in all the IT classes but that the focus on questioning, problem solving and viewing problems from different perspectives seemed the most prominent.

Viewing results in conjunction with the qualitative results it is possible to note a discrepancy between what is experienced and what is exhibited. This discrepancy as well as the counter-intuitive results are subsequently explored.

5. DISCUSSION OF RESULTS

Although qualitative findings point to the assumption that CTI infused into PP would elicit the most significant results in terms of SDL, quantitative findings prove otherwise. Communicating with peers

gave IT learners the opportunity to stimulate more SDL aspects which could explain why their teachers made much more mention of SDL in their classes compared to the other group. From the results reported above it becomes evident that certain results were counter-intuitive. We see that by deliberately implementing CTI, IT learners' CT and SDL actually decreased, although several researchers (Facione, 1990; Halpern & Marin, 2011**)** reported that deliberate CTI holds the key for CT development. Although these results seem disconcerting, it is important to note that certain variables may have caused these findings:

- It is not evident whether teachers implemented the CTI or CTI infused into PP as asked as no classroom observation was done. IT teachers were less convincing regarding their learners' progress in SDL and CT. This finding may be an indication that teachers had less confidence in their implementation and their results. Brookfield (2012) emphasizes that teachers should model CT; however from these results one can deduce that teachers may not have modeled the CT and SDL as needed.
- From literature regarding SDL it is clear that learners should acquire the ability to be self-directed in their learning (Knowles, 1975). By forcing learners to follow set rules and steps, the freedom to become self-directed may have been inhibited.
- According to Grow (1991), SDL development is a gradual process. CT development also requires time as it is hard to develop CT skills (Halpern, 2003; Dunn et al., 2008). The short amount of time given between measurements may have had an impact on the results as only six weeks were available to implement the suggested strategies in the IT classes.
- Taking into account that teachers are constantly under pressure to complete the prescribed curriculum in time, implementing a new intervention may place stress on learners and teachers which might have caused a counter-productive result.

In future investigation, we would extend the period of interventions to determine whether the CTI and CTI infused into PP interventions would not yield greater results. Furthermore, classroom observations could assist in monitoring teachers' implementation of the interventions.

6. CONCLUSION

Scholarship on SDL and CT notes that both these aspects can be developed but that it remains a challenging endeavor which takes time and deliberate input. From this investigation it also became evident that engaging learners in a too strict strategy (where they are forced to follow steps) may be counter-productive to their SDL and CT development. Engaging students in CTI infused into PP increases the likelihood of CT and SDL development, although the set rules of the CTI may still inhibit its development. The most surprising result found in this investigation is the fact that no CT development occurred regardless of the deliberate CTI.

The overwhelming response from teachers and learners in the qualitative investigation indicates a definite awareness of CT and SDL. This is an indication that the CTI intervention should not summarily be dismissed and further research should be done in this regard.

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