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Critical Thinking and ICT Integration in a Western Australian Secondary School

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ABSTRACT
This study examined the relationship between students working in a technology-rich environment and their development of higher order thinking skills. Based on a PhD thesis, which examined a greater range of relationships than can be reported here, this article focuses on developing critical thinking skills within a technology-rich environment. Staff and students from one school participated in the study. Data were collected to determine the degree of correlation between factors of the learning environment and the extent to which critical thinking skills were demonstrated by the students. Statistical correlations allowed relationships between environmental factors and critical thinking to be established. The results indicate that there are statistically significant correlations between studying within a technology-rich learning environment and the development of students' critical thinking skills. Length of time spent in the environment has a positive, non-linear effect on the development of critical thinking skills. Students with better developed computing skills scored higher on critical thinking activities. This was most significant for students with better computer programming skills and the ability to competently manipulate Boolean logic. The research suggests that to develop students' higher order thinking skills, schools should integrate technology across all of the learning areas. This will allow students to apply technology to the attainment of higher levels of cognition within specific contexts. This will need to be paralleled by providing students the opportunity to develop appropriate computer skills.

Keywords
Critical thinking, Higher order thinking skills (HOTS), Computer technology as a learning tool

Introduction

The International Conference on Computers in Education (ICCE, 2002) generated over 400 papers. Many of these detailed how ICT can be applied to higher order thinking skills, including Agnew (2002), Lee (2002) and Thomas (2002). Agnew (2002) iterated that researchers have tried to evaluate whether or not the use of technology has a major impact on student learning. Agnew (2002) continues by explaining that students are encouraged to develop higher order thinking skills, and that the results have been significant. However, no formal statement about how the achievement of these skills have been observed or measured has been made. While the application of notebook and/or hand-held computers within the learning environment has been examined at the tertiary level (Hewlett-Packard, 2004; Edith Cowen University, 2005) this area of research is in its infancy in secondary education, and little has been conducted within Western Australian secondary schools. Sherry and Jesse (2000) suggested that while educators seem to inherently 'know' that technology increases student achievement, measuring the increase is challenging. Branigan (2000, in Sherry & Jesse, 2000, p. 2) reported that in cases where teachers have applied a high degree of technology within the classroom, standardized test scores also were high. Trucano (2005) supports this argument, reporting that the application of Computer Aided Instruction (CAI) packages has resulted in improved test scores for mathematics and reading. However, he queries that these increased scores are indicative of a general increase in student learning. As schools have a far more important role than simply producing good test scores these results do not necessarily provide insight into overall student development. Trucano (2005) continues by arguing that, despite the results of many studies, the influence of ICT on student achievement is still difficult to measure.

This argument is reinforced by Sharma and Haigh (2008) who conducted a case study to examine how ICT is used to develop pedagogy. They concluded that the overall effect of ICT was difficult to isolate, due to the influence of other learning environment factors. Other studies have incorporated learning environment factors. Wanpen and Fisher (2004) used qualitative and quantitative techniques to assess the extent to which constructivism has been incorporated within computer classrooms, and to provide goals for further development. They concluded that it is possible to manipulate factors of the learning environment to make it more conducive for study in computer classes. Student reflections suggest that they found small group work helpful, demonstrating the value of a collaborative approach to learning.

Whilst examining the qualitative elements of a technology-rich environment, O'Dwyer, Russell, Bebell and Tucker-Seeley (2008) argued that traditional methods of assessing student performance may not be valid when technology is used. Existing instruments tend to measure critical and/or creative development in general terms, whereas technology is usually applied to specific learning areas (Russell, 2002, in O'Dwyer, Bebell, & Tucker-Seeley, 2008).

A similar argument was forwarded by McNabb, Valdez, Nowakowsk, and Hawkes (2004). In their study of the application of technology to the development of mathematics and science education, the use of standardised testing is criticised. Instruments such as the California Achievement Test and Illinois Measure of Annual Growth Exam do not evaluate higher order thinking or technology skills, or the context in which these skills are developed.

To determine the relationships between ICT application, and other factors within the learning environment, and the development of higher order thinking skills, this paper examines the questions:

1. To what extent is computer-based technology integrated in the teaching-learning environment?
2. Is there a significant correlation between the students' computer skills and the
   - 2.1. development of critical thinking skills?
   - 2.2. length of time spent within the environment?
   - 2.3. age of the technology?
3. Is there a significant correlation between the length of time spent within technology-rich environment and the development of critical higher order thinking skills?
4. Is there a significant correlation between the age of the technology and the development of critical higher order thinking skills?

For the purposes of this paper, higher order thinking skills are defined as those mental processes that allow students to develop factual, procedural, conceptual and metacognitive knowledge within the creative and critical domains described by Anderson and Krathwohl (2001).

Method

The approach taken by this research is that of a case study. Staff and students from one school participated in this case study. Data were collected by teachers as part of the normal teaching-learning program, supplemented by classroom observations and teacher interviews. The data were used to determine the degree of correlation between factors of the learning environment and the extent to which higher order thinking skills (HOTS) were demonstrated by the students. Collations of the statistically significant, and statistically insignificant, correlations allowed relationships between specific environmental factors and HOTS to be established.

The data source was the Year Nine student cohort in a metropolitan, independent girls' school, providing a sample size of approximately 150 students. This school had been implementing a notebook computer program for nine years, in which all students in Years Five through to Year Ten use their notebooks across all learning areas, every day at school. The majority of students enrol in the junior years, although about one third of students begin in Years Seven and Eight, and approximately twelve students enrol in Year Nine. The Year Nine cohort constitutes students that have had between one and five years exposure to the technology-rich learning environment. Some students will buy a new notebook computer after three years; others will economise by keeping their original notebook computer for six years. Data about the length of enrolment at the school, and the age of their current notebook computer, are held within the school's databases.

The instruments used were the

- Level of Technology Implementation (LoTI);
- Australian Schools Computer Skills Competition (ASCSC); and
- Ennis' Weir Critical Thinking Essay Test (EWCTET).

The extent to which the learning environment can be considered as technology-rich was determined by implementing the LoTI process (Moersch, 1999). The LoTI instrument is used to calculate the level of computer efficiency of an institution. It draws on quantifiable data obtained through observations and structured interviews (Moersch, 2003).The different levels are summarised in Table 1.

Table 1: Description of LoTI Levels

Level	Pedagogy
0	Little or no computer use
1	Technology-based instruction is predominately *about* the technology
2	Technology use is peripheral or dispensable
3	Technology use is adapted to fit with traditional goals
4	Technology is used for collaborative instruction
5	Technology supports self directed, collaborative learning
6	Technology supports self directed, collaborative learning; students & teachers are learners and researchers

The technology skills of students were determined from the externally marked ASCSC. The ASCSC is a national test that students sit annually. The competition is designed to assess students' computer skills and knowledge outlined in the various State curricula.. The questions reflect the importance of the higher order thinking skills, and present an opportunity for students to perform a range of tasks using these skills. Measures of the ASCSC produced Cronbach's alpha coefficients ranging from 0.55 through to 0.70 (McMahon, 2007), which suggests that the ASCSC (2005) provides a reliable means of measuring students' computer skills.

The EWCTET requires student to formulate a complex argument in response to an earlier argument. In doing so the test measures the student's ability to analyse an argument and provide a logical, coherent response, including creative and critical dimensions (Ennis & Weir, 1985). In a later paper (Ennis, 1998) the test is reported as being valid and reliable, with inter-rater reliabilities in the order of 0.72 – 0.93.

Data concerning students' length of enrolment at the school, and the age of their computers, were extracted from the school's databases. The ASCSC and EWCTET were marked according to predetermined answers keys. Whilst the ACSCS marking key is prescriptive the EWCTET allows for some teacher judgment. All of these instruments provide a raw numerical score. Data analysis involved the correlation of results to determine the relationships that exist between the different learning environment factors.

Questions two, three and four were framed as a series of hypotheses that could be accepted or rejected based on statistical analysis:

1.1 H_0: There is no significant correlation between students' computer skills and the development of critical thinking skills.
H_1: There is a significant correlation between students' computer skills and the development of critical thinking skills.

1.2 H_0: There is no significant correlation between students' computer skills and the length of time spent within the environment.
H_1: There is a significant correlation between students' computer skills and the length of time spent within the environment.

1.3 H_0: There is no significant correlation between students' computer skills and the age of the technology.
H_1: There is a significant correlation between students' computer skills and the age of the technology.

2 H_0: There is no significant correlation between the length of time spent within technology-rich environments and the development of critical thinking skills.
H_1: There is a significant correlation between the length of time spent within technology-rich environments and the development of critical thinking skills.

3 H_0: There is no significant correlation between the age of the technology and the development of critical thinking skills.
H_1: There is a significant correlation between the age of the technology and the development of critical thinking skills.

For the purposes of testing the hypotheses, correlation coefficients between data gained from these instruments were calculated. The correlations were determined by calculating Spearman's correlation coefficients relevant to each research question. ASCSC scores were recorded as student percentile rankings; for consistency between the sets of correlations, Spearman's rho was calculated in place of Pearson's r. Data from the instruments were reinforced with data collected from staff and student interviews, and classroom observations. Concurrently, the LoTI instrument (Moersch, 1999) was used to quantify the technology use within the school and therefore determine the level at which the school is operating, with respect to technology integration.

Results

Technology Integration

The data in Tables 2 and 3 indicate that technology is predominantly used at Levels Four and Five, as measured by the LoTI scale, which suggests an emphasis on lessons that implement technology used across the learning areas to address higher orders of learning.

Table 2: LoTI Computer Efficiency Rating Chart*

Descriptor	Level	Learner Use %	No. of Computers	Product (B x C x D) / 100
A	B	C	D	E
Non-use**	0	33.33	291	0.00
Awareness	1	4.87	291	14.17
Exploration	2	8.53	291	49.64
Infusion	3	15.13	291	132.08
Integration	4	18.53	291	215.69
Expansion	5	12.07	291	175.62
Refinement	6	7.54	291	131.65
Total		100.00	291	718.85
F	718.85 / (291 x 4) = 0.62		Computer Efficiency Rating = 62%	

*Data were collected by an anonymous survey.

**Non-use includes time spent on classroom administration (E.G. roll call), introducing the lessons, giving instructions to students and concluding lessons.

Table 3: LoTI Computer Efficiency Rating Chart*

Descriptor	Level	Learner Use %	No. of Computers	Product (B x C x D) / 100
A	B	C	D	E
Non-use**	0	33.33	25	0.00
Awareness	1	0.77	25	0.19
Exploration	2	3.83	25	1.92
Infusion	3	13.79	25	10.34
Integration	4	28.35	25	28.35
Expansion	5	8.43	25	10.54
Refinement	6	11.50	25	17.25
Total		100.00	25	68.59
F	68.59 / (25 x 4) = 0.68		Computer Efficiency Rating = 68%	

* Data were collected through direct classroom observation.

**Non-use includes time spent on classroom administration (E.G. roll call), introducing the lessons, giving instructions to students and concluding lessons.

Assessing the level of technology integration is not an exact science. Classroom observations require the approval of the teacher. Within an environment that promotes technology, there could be some reluctance to allow observations in a classroom that may not promote technology integration. Those teachers that readily accept observations of their lessons are likely to be those who confidently and gainfully employ technology in their classes.

To address this predicament, data for the LoTI evaluation were collected by two methods. Data in Table 2 was collected by an anonymous survey, in which teaching staff indicated the types of activities that were occurring in their classes. Data in Table 3 was collected through direct classroom observations across eight learning areas. LoTI efficiency ratings were then calculated based on both sets of data. While there is no statistical test that can be used to determine the significance of this data, the two calculated efficiency ratings of 68% and 62%, shown in Tables 2 and 3 are close, which suggests that these approaches are reliable. The efficiency rating between 60% and 70% indicates a high level of computer integration across the learning areas.

Computer Skills

Table 4 shows that, on average, the research cohort scores are 2% higher than the State mean scores. Furthermore, the research cohort has greater than 40% of its students in the top 30% of the State scores,

Table 4: Comparison of Mean ASCSC Scores 2005-06

Year		School	State	% of School Cohort in the State:		
				50%	30%	10%
2005	Mean Score ($^x/_{45}$)	24.1	22.7	58.9	40.8	11.2
	N	404	1326			
2006	Mean Score ($^x/_{45}$)	20.0	18.8	66.3	40.8	11.6
	N	380	1577			

Prior to 2005 students entered this competition on a voluntary basis, resulting in low numbers relative to later years. Student performance for 2002-03 compared to the State are summarised in Table 5.

Table 5: Comparison of Mean ASCSC Scores 2002-03

Year		School	State
2002	Mean Score ($^x/_{45}$)	27.5	25.3
	N	19	1846
2003	Mean Score ($^x/_{45}$)	29.7	27.9
	N	56	1357

Whilst Table 5 indicates a higher mean result for the school than for the State, this may not be a true reflection of the students' level of computing skills. As the test was sat by volunteers, it could be argued that the volunteers had an 'above average' interest in technology, which could inflate the school's results. However, this could also apply to the students of other schools involved in the test.

The 2% difference between the mean results for the school and State has been maintained when the complete cohort is considered in Table 4. Furthermore, 40% of the school cohort results lie within the top 30% of the State results. Eleven percent of the school cohort lies within the top 10% of the State results. This can be further analysed using the Chi-squared test of the hypotheses:

H_0: There is no significant difference between the observed and expected mean values.
H_1: There is a significant difference between the observed and expected mean values.

Chi-squared values are shown in Table 6.

Table 6: Chi-Squared Value for the School Cohort

	% of School Cohort in the State:		
	50%	30%	10%
Observed	66.3	40.8	11.6
Expected	50.0	30.0	10.0
Chi2		9.491**	

** Significant at the 0.01 level

The calculated Chi-squared value in Table 6 indicates that the null hypothesis (H_0) should be rejected, in favour of the alternate hypothesis (H_1), that there is a significant difference between the observed and expected mean values. The scope of technology integration in the 'State' cohort is unknown. The effect of cultural differences between the environments that may affect the test results are not reported here. Those who are interested are directed to http://adt.curtin.edu.au/theses/available/adt-WCU20070525.172626/.

Critical Thinking Skills

Three groups of students were video recorded as they completed the EWCTET, to identify the different levels of cognitive activity described by Anderson and Krathwohl, (2001) that they employed. Cognitive activity was determined from the questions asked of the teacher, discussions between students, and their behaviour during the task. Examples are shown in Table 7.

Table 7: Observations of Anderson and Krathwohl's Cognitive Dimension

Cognitive Dimension	Knowledge Dimension	Example of student dialogue and/or activity
Disengaged*		[Discussion of TV shows]
Remembering	Factual	I'm not sure what we have to do We have to read the letter
	Conceptual Procedural	Do you choose one of them [Tasks]? No, you have to do both.
	Metacognitive	-
Understanding	Factual	[Listening to instructions]
	Conceptual Procedural	Are we supposed to put down our own objections and things?
	Metacognitive	So, we're responding as though this letter was written to us.
Applying	Factual Conceptual Procedural Metacognitive	[Working on set task following prescribed format – identifying, clarifying and responding to a point of view]
Analysing	Factual	From [paragraph] five onwards it's all about accidents. He's using a lot of facts, but it's too much facts because it's kind of the same thing
	Conceptual	I don't get what it means by … [Reads aloud from task]
	Procedural	-
	Metacognitive	I disagree with this point here. [Points to screen]
Evaluating	Factual	It's not very clear. [The argument]
	Conceptual	Explains personal response to presented arguments to partner, relating to authentic conditions close to the school
	Procedural	-
	Metacognitive	The debate is not good – he needs to get proof The person needs to write the letter more clearly so that whom he is sending it to can understand it better.
Creating	Factual	-
	Conceptual Procedural	Make it that they have to pay for it, or get a parking ticket.
	Metacognitive	Maybe they could widen the streets by taking out the pathways. [Elaborates in detail, based on personal knowledge of a similar situation in rural Australia]

*Disengaged activities are those that occur when students engage in activities not related to the assignment

The time each group of students spent operating at the different cognitive levels is shown in Table 8.

Table 8: Occurrences of Anderson and Krathwohl's Dimensions

	% Lesson time at each level		
		Group	
Level	1	2	3

Disengaged	46.8	32.9	20.3
Remembering	13.3	19.9	11.8
Understanding	3.3	1.3	2.5
Applying	32.1	45.9	37.6
Analysing	4.6		18.6
Evaluating			4.7
Creating			4.5
	100.0.	100.0	100.0

Students' performances for this task are shown in Table 9.

Table 9: Student Performance for the EWCTET

	Critical Thinking Skill								
Marks	Recognise False Analogy	Recognise Irrelevant Argument	Recognise Correct Argument	Recognise No Support	Recognise Alternative Arguments	Recognise Poor Experimental Design	Recognise Poor Definition	Recognise Emotive Language & Provide Coherent Summary	Total
Maximum Possible	3.00	3.00	6.00	3.00	3.00	3.00	3.00	5.00	29.00
Maximum Gained	3.00	3.00	6.00	3.00	3.00	3.00	3.00	5.00	*21.01
Average	0.45	0.58	2.33	0.71	0.79	0.86	0.75	0.54	**5.96

* This is the highest score attained by a student, not the sum of the maximum scores gained by the student cohort
** This is the mean total score, not the sum of the mean scores for each question

When addressing the issues raised in the EWCTET students did not automatically move to a level of higher cognition. Recorded observations between students indicate that they move to higher order thinking from a basis of lower order thinking during the early stages of the lesson. All observed groups spent time at the lower taxonomic levels of Anderson and Krathwohl (2001), and the interactions between the students allowed them to achieve higher order thinking skills. It was not always possible to clearly identify the dimension into which student dialogue or behaviour belonged. This resulted in some of the dimensions be merged and others apparently unaddressed.

Group One spent little time in studying the arguments to be addressed. Instead, they launched into their response at a low cognitive level and spent most of their time engaged at the *applying* level, frequently reverting to off-task behaviour. This group was engaged at an analysis level, the lowest of the higher cognitive levels, for less than five per cent of the class time, and did not reach a higher level of engagement.

The short bursts of time spent at the *applying* and *analysis* levels were quickly followed by off-task activities. This group would often ask members within the group questions such as "What does this mean?" or "What do we do here?" indicating a poor understanding of the task.

Group Two followed a similar pattern of off-task and low-cognitive activity. The first 17 minutes of the lesson were spent discussing the requirements of the task at *remembering* and *understanding* levels, alternating with off-task behaviour. It is probable that this would have continued for a greater proportion of the lesson had not the teacher intervened and re-focussed their activities. However, this group continued to struggle with the task, and at no stage were they observed to be operating at a level higher than *applying*.

Group Three displayed a learning pattern that suggests better personal organisation, better understanding of the task, and the ability to operate at higher cognitive levels. The early stages of the lesson were characterised by quiet reflection of the task, followed by group discussion in which the requirements were clarified. This was followed by discussions indicative of higher order thinking as described in Table 7. After higher level discussions the group appears to move to a lower cognitive level (*applying*) during which they are using their discussion to form their critical thinking responses.

Data in Table 9 initially suggest that the general level of critical thinking skills is low. An average score of $^{6}/_{29}$ is considerably short of the generally accepted 'pass mark' of 50%, or $^{15}/_{29}$. It should be remembered that the EWCTET is designed for secondary and tertiary students (Ennis & Weir, 1985). It is reasonable to assume that tertiary students would, on average, perform better than secondary students. Therefore an acceptable pass mark for tertiary students would be higher than that for those still at a junior grade, secondary level.

Rather than considering the test in terms of *pass* or *fail*, it can be viewed as an open-ended instrument. Data from previous administrations of the EWCTET is shown in Table 10 (Ennis, 1998).

Table 10: Mean Scores for the EWCTET

Source	Age Group	Number of Students	Mean Score
Davidson & Dunham (1996)	1st Year, Junior College	19	6.6
		12	4.3
		14	1.8
		10	4.7
Hatcher (2004)	1st Year University	169	6.3
		119	9.4
		178	6.8
		178	8.1
		164	7.5
		169	6.9
Hatcher (1995)	Final Year University	66	9.6

If the data Table 10 are compared with the data from Table 9 (mean score = 5.96) it appears that the general standard of critical thinking skills transcends the critical thinking skills of college level students. When examining the thinking skills measured by the EWCTET, the highest mean scores relate to the students' ability to recognise a logical argument and arguments involving experimental design. Whilst critical thinking skills are not specifically taught within this learning environment, all students were in their third year of science classes that do address the scientific method, which includes the accurate design and execution of experiments.

Within the researched learning environment, science classes use technology extensively. Spiro's cognitive flexibility theory (Spiro, Feltovich, Jacobson & Coulson, 1991), explains how students can restructure their thinking as a means of adapting to new situations (Swindler, 2001). Swain, Greer and van Hover (2001) argue that the flexibility provided by computers make them an ideal learning tool employing the cognitive flexibility theory. It seems evident that students are transferring their critical thinking skills, developed within a technology-based science education environment, to other learning situations.

Data in Tables 4 and 5 indicate that above average computer skills exist within this learning environment when compared to those of the State. Similarly, data in Tables 9 and 10 indicate above average critical thinking skills within this learning environment. Spearman's Correlations between the factors within the technology-rich learning environment are shown in Table 11.

Table 11: Spearman's Correlations for the Learning Environment Factors

		EWCTET	Length of Enrolment	Age of Computers
ASCSC	Rho	0.307**	0.154*	0.039
	N	116	135	133
Length of Enrolment	Rho	0.036		
	N	131		

Age of Computers	Rho	-0.050
	N	128

* Significant at the 0.05 level
**Significant at the 0.01 level

Reject the null hypothesis (1.1: H_0). Accept the alternate hypothesis (1.1: $H_{1,}$) that there is a significant correlation between students' computer skills and students' critical thinking skills.

Reject the null hypothesis (1.2: H_0). Accept the alternate hypothesis (1.2: H_1) that there is a significant correlation between students' computer skills and their length of time within the environment.

Accept the null hypothesis (1.3: H_0). There is no significant correlation between the age of the students' computers and the development of students' computing skills.

Accept the null hypothesis (2: H_0). There is no significant correlation between students' critical thinking skills and their length of time within the environment.

Accept the null hypothesis (3: H_0). There is no significant correlation between the age of the students' computers and the development of students' critical thinking skills.

The EWCTET examines different aspects of critical thinking. This test cannot be reliably broken into these aspects but it can be treated as a reliable measure of critical thinking in total (Ennis & Weir, 1985; McMahon, 2007). The ASCSC is designed with questions that specifically address different scales of computer skills, and these scales have been shown to be reliable by McMahon (2007). Correlations between the score for these computer skill scales and scores for critical thinking are shown in Table 12.

Table 12: Spearman's Correlations for Critical Thinking and the Scales of Computer Skills

		ASCSC scales					
		Productivity Tools	Internet	Communication	Hardware	Software	Programming
EWCTET	Rho	0.108	0.229**	0.231**	0.034	0.196*	0.212*
	N	116	117	116	117	116	117

*Correlation is significant at the 0.05 level (1-tailed)
**Correlation is significant at the 0.01 level (1-tailed)

The data show that the correlations are not significant for all of the scales used to measure students' computer skills. The greatest significance occurs for those scales that address higher order thinking skills, for example, the Internet and Programming scales. These scales require students to be able to apply Boolean logic, and analyse and evaluate programming script.

In the researched learning environment there are intakes of new students each year. By dividing the Year Nine cohort into series of groups, statistical analysis between the series of groups is possible. The cohort was divided into students with less than one year in the environment and greater than one year; less than two years, greater than two years; and so on up to less than nine years, greater than nine years. Statistical correlations for these groups are shown in Table 13 and Figure 1.

Table 13: Spearman's Correlations for Length of Enrolment and EWCTET

		Length of Enrolment (Years)								
EWCTET		*>=1*	*>=2*	*>=3*	*>=4*	*>=5*	*>=6*	*>=7*	*>=8*	*>=9*
Rho	<1	0.080								
Rho	<2		-0.115							
Rho	<3			0.114						
Rho	<4				0.098					
Rho	<5					0.157*				
Rho	<6						0.157*			

Rho	<7	0.183*		
Rho	<8		0.183*	
Rho	<9			0.170*

*Correlation is significant at the .05 level (1-tailed).   N = 132

Figure 1 provides a graphical representation of these correlations, from which a second order polynomial line-of-best-fit can be inferred. This describes the general trend between the length of time spent in the environment and the development of critical thinking skills.

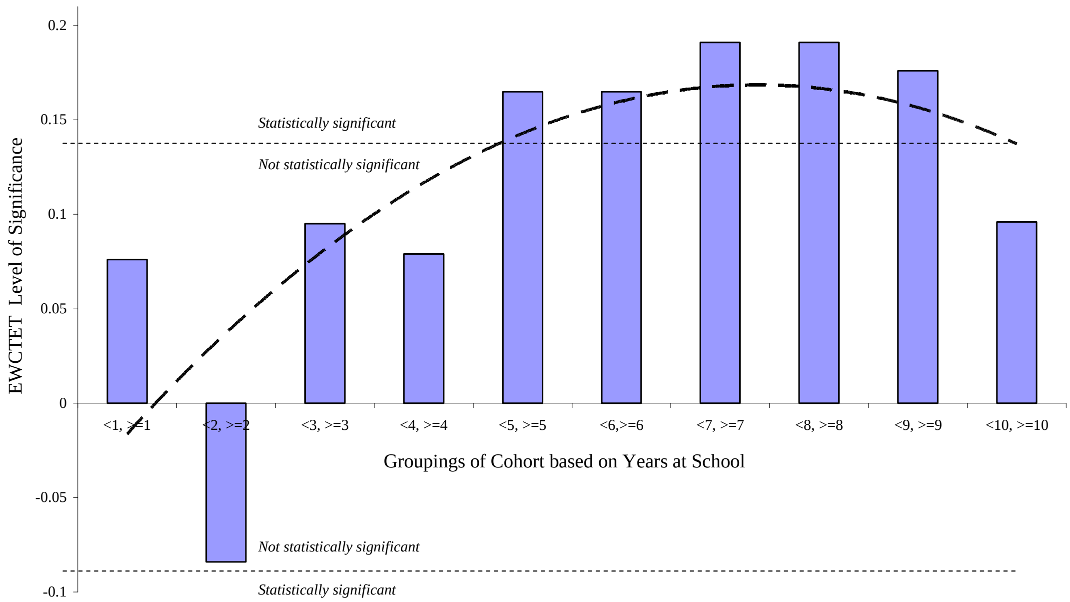

Figure 1. Correlations for EWCTET and the length of enrolment

Discussion

Papert (1972) imagined an educational environment in which students used computers as an extension of their mind. An advocate of teaching children how to program computers with Logo, Papert believed that the logical nature of programming coupled with the imaginations of children allows them to understand abstract principles by addressing them within a concrete framework. The data in Table 12 support this belief; students with better developed programming skills, developed within a technology-rich environment, score higher on critical thinking exercises. While this is not to state that the better programming skills cause higher order thinking, it should be noted that the computer skills are explicitly taught within this educational environment. Higher order thinking skills are not.

The data show a significant statistical correlation between the length of time students spend in the technology-rich environment and the development of their computer skills. It could be expected that, given this correlation, there would also be a significant statistical correlation between the students' computer skills and the age of the computers.

Paradoxically, it could be argued that older computers are less reliable or efficient than more recent models, which could have a negative effect on the students' learning and development of computer skills, yet there is no significant statistical correlation, positive or negative, between students' computer skills and the age of the technology.

An important component of this technology-rich learning environment is the comprehensive technology support offered, in terms of hardware maintenance and software updates. Irrespective of the age of the notebook computers, the turn-around time for repairs is low, most being returned to the students on the same day. When a student's computer is being repaired the student is immediately given a replacement, in order that she may continue her lessons with minimal disruption.

One function of the Learning Technologies department within this school is to actively search for software to assist students' learning. Any potential package is then tested on the different notebook models to ensure that is will perform adequately. When the software updates and hardware maintenance are considered, the insignificant statistical correlation between the age of the computer and the development of higher order thinking skills is understandable. Certainly, there may be some angst from students enviously regarding their fellow students' latest acquisition, but this effect is minimal.

Teaching specific skills related to computer programming enhances students' attainment of higher order thinking skills. The programming skills include developing an understanding of Boolean logic, top-down approaches to solving problems and exploring data manipulation from novel dimensions. The development of computer skills within a socially constructivist, technology-rich environment allows students to attain higher order thinking skills on par with tertiary level students.

Schools should endeavour to integrate technology across all of the learning areas. This will allow students to apply technology to the attainment of higher levels of cognition within specific contexts. If students are to apply computer-based technology to their studies they must be given the opportunity to develop appropriate computer skills. As demonstrated by the data, this does not necessarily require the latest model computers. The power of computers in education lies in embedding them in the curriculum and not using them as embellishments.

O'Dwyer, Russell, Bebell and Tucker-Seeley (2008), and McNabb et al. (2004), contended that traditional methods of assessing student performance measured higher order thinking in general terms rather than in specific learning areas to which technology is applied. Within this study groups students used technology extensively within the English learning area, and it is within this area that the EWCTET measures critical thinking.

There is no simple linear correlation between the length of enrolment in a technology-rich environment and the development of critical thinking skills. Closer analysis of the data provides more illumination. Table 13 shows that there is a significant statistical difference in the critical thinking skills (as measured by the EWCTET) of students who have been immersed in a technology-rich culture more than five years when compared to those who have been a part of the same culture for less than five years. This difference is maintained for students who have been a part of the culture for more than six, seven, eight and nine years. The cultural experiences from pre-school and/or kindergarten are not statistically significant with respect to critical thinking in Year Nine.

The data shown in Table 13 and Figure 1 suggest that there is a negative influence of the socio-cultural environment on the development of critical thinking for students with less than two years immersion in the environment. Adeyemo (2005) describes how a transition into secondary school is associated by a decline in academic achievement. This is not a new phenomenon, having been previously reported by Maehr (1974).

Maehr describes how our social experiences affect the perception of our environment and therefore affects the acquisition of knowledge. As the social group to which a student belongs is changed, achievement also changes. In a more recent study, Tonkin and Watt (2003) have associated the decline in academic performance with both the transition to a new environment and the onset of adolescence. Given that all of the students in this research cohort are of the same age group, the adolescent factor is negated. There is greater influence from moving into a new environment. Students moving into this technology-rich environment have an added burden related to the use of technology in all of their classes. Being unfamiliar with the protocol of electronically delivered learning materials, and even unfamiliarity of the technology itself, initially detract from their ability to achieve higher cognition with the technology.

At this point a caveat needs to be added. The population sample sizes used in this research were around 150, which may be considered large. Spencer (1995) argued that statistically significant correlations derived from large samples do not necessarily have a practical value. If the results are statistically significant, but small, then the cost of implementing the results in a social setting may not be justifiable (Morgan, Leech, Gloeckner & Barrett, 2006). Cohen (1992) suggested that the practical significance of statistical correlations with values of 0.1, 0.3 and 0.5 should be considered small, medium and large respectively. Accordingly, the statistically significant correlations presented in this paper would be regarded as having a small to medium practical significance. Schools considering implementing a school-wide computer integration program would need to closely examine the associated costs with the perceived benefits. The intention of the Australian Labor Party to provide a laptop for every student (Winterford, 2007) implies that such programs are justified, although the debate is not yet over (Parker, 2008).

Conclusions

There is a statistically significant correlation between students' computers skills measured by the ASCSC and their level of critical thinking skills measured by the EWCTET. The correlation exists between critical thinking skills and higher order computer skills, represented by the ASCSC scales of Internet and Programming. Students with better computing skills demonstrate a higher level of critical thinking.

These results address the concerns of Agnew (2002) and Trucano (2005) by providing data that links the use of technology to student learning. The instruments used – the ASCSC and the EWCTET – have been demonstrated as a reliable and valid method of measuring this relationship.

There is a statistically significant, positive correlation between the length of time that students spend in the technology-rich environment and their development of computer skills. Regular updating of software, and a well-established hardware maintenance program, mean that there is no statistically significant correlation between the age of the technology and the development of computer skills. The use of applications packages allows students to quickly and accurately process data, and therefore create knowledge. Time saved permits more time to be spent exploring specific subjects at deeper levels; exploration which is further enhanced by using the technology.

The statistically significant correlations are low and/or medium, as described by Cohen (1992). Further research is necessary to establish the practical significance of these findings.

While technology skills include the lower level manipulation of applications programs, they include developing higher order skills such as computer programming. Using productivity tools effectively allows subjects to be explored in greater detail. Computer programming develops skills in logic, critical thinking and creative thinking. This research indicates that the technology has a greater influence on critical thinking. Application of computing to assist the development of creative thinking needs to be further developed. Consideration should also be given to the establishment of technology-based teaching-learning programs to develop generic higher order thinking skills.

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