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Deepening and transferring 21st century learning through a lower secondary Integrated Science module

A secondary school in Singapore incorporated 21st century learning into their science curriculum through an inquiry-based Integrated Science module. This study examines secondary two students' perceptions of 21st century learning through this module. Through pre and post study surveys of 227 students and focus group interviews with nine students, it was found that the Integrated Science module deepened students' confidence with self-directed learning and authentic problem-solving whereas students' confidence with critical thinking positively predicted students' end-of-year results. Through this module, students acquired skills related to time management, information analysis, the use of information communications technologies and presentation that they transferred to the learning of their other academic subjects. The implications for designing 21st century learning experiences in schools are discussed.

Keywords: 21st century learning; STEM; student evaluation; learning transfer; 21st century skills

Introduction

The need for schools to help students foster 21st century competencies for productive contribution to the increasingly complex and dynamic environments in globalized information economies has been repeatedly emphasized (e.g. Binkley et al., 2010; OECD, 2005; P21, 2007). In an analysis of the different 21st century frameworks, authors such as Voogt and Roblin (2012) defined 21st century competencies as encompassing skills such as social-cultural competencies, critical thinking and creative thinking skills for metacognition and problem-solving, technological skills for exploiting information and communication technologies (ICT), and productivity skills for organizing and executing work processes efficiently and effectively. Correspondingly, 21st century learning are the learning experiences that help students to develop the different kinds of 21st century competencies (Koh, Chai, & Lim, 2016).

Despite the proliferation of theoretical conceptions about 21st century learning (e.g. Howland, Jonassen, & Marra, 2013; Koh, Chai, Wong, & Hong, 2015), there are still no established models of 21st century learning pedagogies in schools (Voogt, Erstad, Dede, & Mishra, 2013). Correspondingly, evaluation studies examining the effects of 21st century learning experiences on students are also rare. Inquiry-based learning can be one way for students to acquire 21st century competencies (Alozie, Grueber, & Dereski, 2012). With economies increasingly driven by innovation and technology, preparing students with the 21st century competencies to undertake STEM (science, technology, engineering, and mathematics) careers has gained prominence in science education (Gu & Belland, 2015).

This study therefore first describes the design of a lower secondary science curriculum carried out in a four-year Singapore secondary school which seeks to deepen students' engagement in 21st century learning through the use of an Integrated Science module with authentic investigative projects integrating content from the three main disciplines of Science – Biology, Chemistry and Physics. It then reports the implementation outcomes of the module with data collected from 227 secondary two students in the school. Guided by the evaluation dimensions of Kirkpatrick and Kirkpatrick (2006), this study examines students' reaction, learning, and transfer of learning with respect to the Integrated Science module. Mixed methods comprising of pre and post-study student surveys, analysis of student test scores for Science, as well as focus group interviews with nine students were used to implement the study. The implications for designing 21st century learning in schools are discussed.

Literature review

Dimensions of 21st century learning

21st century learning seeks to prepare future-ready students with the creative and innovative potential to cope with a changing world (Kaufman, 2013). To date, established models of 21st century learning are not yet pervasive in schools (Voogt et al., 2013) but researchers largely converge on the dimensions that could embody 21st century learning. Chai, Deng, Tsai, Koh, and Tsai (2015) propose that critical thinking, creative thinking, and authentic problem-solving are the key thinking processes that could be instantiated during 21st century learning. Critical thinking refers to the ability to analyse and reason deeply through the use of evidences and argument (Elder & Paul, 1994) whereas creative thinking refers to the ability to generate useful innovations (Sternberg & Lubart, 1996). Authentic problem-solving defines the context whereby students engage in critical thinking and creative thinking to solve what Jonassen (2000) describes as ill-structured and complex problems with multiple possible solutions. Therefore, 21st century learning helps students to become workplace-ready through applying their thinking skills to solve real-world problems.

With social-cultural, communication, and conflict resolution abilities deemed as critical 21st century competencies (see Binkley et al., 2010; OECD, 2005), it is logical that 21st century learning also include opportunities for students to engage in collaborative learning. Besides collaborative learning, Chai et al. (2015) also propose self-directed learning to be an important 21st century learning process whereby students learn to engage in self-regulation (Zimmerman, 2008) through taking charge of their learning goals and learning processes. In fact, such kinds of experiences are critical for developing the 21st century competencies of metacognition and self-management that are being emphasized in frameworks described by OECD (2005) and Binkley et al. (2010).

Future-ready workers are those who are savvy in exploiting the appropriate technologies for productive work (Larson & Miller, 2011). The proliferation of ICT makes it imperative that 21st century learning includes technology-integrated learning (Koh et al., 2016). Howland et al (2013) argue that 21st century learning encompasses meaningful learning with ICT where students *learn with* technology as organization, visualization, and thinking tools to facilitate authentic problem-solving. Howland et al.'s framework for meaningful learning with ICT recommends that learning with technology should comprise five dimensions: active learning, constructive meaning-making, authentic problem-solving, collaborative learning, and intentional learning.

Koh et al.'s (2015) review suggest that 21st century learning can be understood as having five characteristics: social-cultural, cognitive, metacognitive, productivity, and technological. Rather than just didactic instruction, it involves the engagement of these various dimensions in the context of authentic problem-solving. Chai et al. (2015) further argued that 21st century learning serves to develop students as "knowledge creators" (p. 391) who are able to use their existing knowledge to create problem solutions. Pearlman (2010) therefore suggest that authentic learning through the use of project-based and problem-based learning are pedagogies that could be used to facilitate 21st century learning.

Inquiry-based learning and 21st century learning

Inquiry-based learning aims to help learners explore scientific problems through structured inquiry phases designed to emulate scientists' inquiry processes (Pedaste et al., 2015). To date, many models for inquiry-based learning are available (e.g. BSCS & IBM, 1989; de Jong, 2006). A review by Pedaste et al. suggest that these models generically start by asking students to generate hypotheses for scientific problems or questions. Students then plan and execute experiments to investigate and evaluate their findings.

There is generally a dearth of empirical studies examining the relationships between inquiry-based learning and 21st century learning. Yet, researchers have noted that many aspects of 21st century learning dimensions could be experienced from inquiry-based learning. Alozie et al. (2012) suggest that inquiry-based learning could enhance students' adaptability, communication skills, problem-solving skills, self-management skills, as well as skills for systems thinking. Crippen and Archambault (2012) suggest that when inquiry-based learning is supported by technology tools and anchored upon real-world problems, it can help students to develop the critical skills required of a 21st century worker. These generally correspond to the social-cultural, productivity and technological skills competencies identified by Koh et al. (2015) as well as the critical thinking, authentic problem-solving, and self-directed learning competencies identified by Chai et al. (2015).

Generating and transferring student outcomes from 21st century learning programmes

To date, there are few studies examining student outcomes from 21st century learning programmes, including Science education. An area that has been studied is students' perceptions of 21st century learning. Anecdotes from Pearlman (2010) report students perceiving 21st century learning as involving dimensions such as thinking ahead, creativity, teamwork, and negotiation which largely corresponds to the 21st century learning dimensions identified in the literature review. In a quantitative study, Chai et al. (2015) found that primary school students' perceptions of critical thinking, creative thinking and authentic problem-solving had greater influences on their confidence for knowledge creation as compared to their perceptions for collaborative learning and self-directed learning. The evaluation of learning is an important dimension for determining the success of training design (Kirkpatrick & Kirkpatrick, 2006). However, studies such as Alozie et al. (2012) describe lesson examples for promoting 21st century skills in the Science classroom but did not further examine students' learning outcomes. Another gap in current research is that we have not found studies examining how students transfer their learning beyond 21st century learning programmes. Voogt, Erstad, Dede, and Mishra (2013) comment that 21st century competencies are "complex and cross-disciplinary" (p. 407). It is also important to note that articulations of 21st century competencies (e.g. OECD, 2005; P21, 2007) are about preparing learners with competencies to become effective future workers. Therefore, when evaluating student outcomes from 21st century learning, it is critical to understand how students are transferring and applying their knowledge and skills beyond their immediate subject-based lesson contexts.

The evaluation of these different aspects of student outcomes can be articulated by drawing upon Kirkpatrick and Kirkpatrick's (2006) model, which proposes for training programmes to be evaluated at four levels: reaction, learning, behaviour, and results. The first level seeks to understand learner reactions in terms of their perception and satisfaction from training. The second level evaluates learning in terms of changes in knowledge, skills, or attitudes. The third level deals with transfer of learning to effect changes in behaviour and practices whereas the fourth level examines the long-term organizational results achieved due to the changed behaviour and practices.

Given the gaps in extant research, this study draws upon the first three levels of Kirkpatrick and Kirkpatrick's (2006) evaluation model to examine student outcomes from a school-based curriculum programme designed to engage students in 21st century learning. This study focuses on the design and implementation of an Integrated Science module conducted by a Singapore secondary school. The first two levels of Kirkpatrick and Kirkpatrick's model will be used to understand students' perceptions of 21st century learning experiences and the learning they achieved respectively. The third level addresses students' behavioural change by transferring 21st century learning to support the learning of other academic subjects. As Kirkpatrick and Kirkpatrick's model is designed for corporate training contexts, the fourth level relates to organizational results that are not relevant for school contexts focusing on education. Therefore, this level will not be addressed in this study.

Research questions

The research questions to be examined are:

(1) How do students' perception of their 21st century learning experiences change before and after attending the Integrated Science module?

(2) What are the relationships between students' perception of 21st century learning experiences and their exam results?

(3) What kinds of learning do students transfer from the Integrated Science module to their other academic subjects?

Methodology

Context

The study was conducted with the Science department of a four-year Singapore secondary school. In 2010, the school reviewed their lower secondary science programme and recognized the need to integrate content from three main disciplines of Science – Biology, Chemistry and Physics so as to enable students to view the interaction of different Sciences in real-life situations. Therefore, the need for an Integrated Science module was conceptualized around an overarching theme of Understanding Environmental Science. The school has three niche areas namely: 1) Chinese Culture and Bicultural Programmes, 2) Performing Arts and 3) Environmental Education. Hence, the Integrated Science module is aligned with the school's niche area for Environmental Education. The core objectives of the module is thus determined as:

(1) To equip students with knowledge about the impact of climate change and global warming to our daily lives
(2) To equip students with knowledge about the importance of conserving the environment
(3) To help students develop 21st century competencies and a mind for scientific enquiry through module activities

The module is compulsory for all Secondary 2 students and builds upon inquiry skills developed during their Secondary 1 science lessons. It is conducted across a year where three hours of classes occur weekly. Table 1 shows the key activities of the lower secondary curriculum and the 21st century learning dimensions that they are designed to support. During Secondary 1, group discussions are held fortnightly to help students better understand concepts taught in Physics and Biology lessons by teachers. The learning of these concepts are further reinforced during practical sessions once a month. Students' learning from these activities culminate in a poster design project during the second half of the year. Conventional paper-and-pencil tests are used to assess students' learning periodically. The same structure is followed during Secondary 2 but students learn to propose and design experiments. They are engaged in mini-investigative projects in groups of four to five. They also attend outdoor learning journeys from February to June, prior to doing poster design.

Table 1. Learning activities in lower science curriculum.

Modules covered	Hours per week	Course activities	21st century learning dimensions
		Secondary 1 Science curriculum components	
1) Physics module 2) Biology module	Three hours, fortnightly for each module	• Group discussions (using demonstrations, videos and animations as triggers) and card games once fortnightly to reinforcing concepts. • Practical sessions for each module about once per month. • Life science workshop on microbiology and poster design in second half of the year. • Paper-and-pencil tests to assess students' learning at the end of each term and end of year examination.	The Practical sessions enable students to develop their inquiry mind and enable them to develop collaborative learning skills. Poster design and group discussions are designed to develop students' competencies in collaborative learning, critical thinking, creative thinking and meaningful learning with ICT. The life science workshop aims to develop students' critical thinking and support students to engage in self- directed learning.
		Secondary 2 Science curriculum components	
1) Integrated Science module 2) Chemistry module	Three hours, fortnightly for each module	• Practical sessions once per month for both modules. • For Integrated Science module, additional activities such as writing investigation proposal from Feb to Mar, mini-investigative projects from Mar to June and learning journeys for all classes in April with deliverables through poster design to share the students' learning. • Group discussions (using demonstrations, videos and animations as trigger) once fortnightly for both modules. • Paper-and-pencil tests to assess students' learning for both modules at the end of each term and end of year examination.	Writing investigation proposal prepares students in the mini-investigative projects. It helps students to reflect on the topics that they want to research on and develop their critical thinking skills. The investigative projects, poster design and group discussions are designed to develop students' competencies in collaborative learning, critical thinking, creative thinking and meaningful learning with ICT. Furthermore, it was envisioned that students will develop authentic problem-solving, self-directed learning and knowledge creation skills through the investigative projects.

Study participants

There were 385 secondary two students who undertook the Integrated Science module in academic year 2016. These students were from ten classes where each class had between 35 to 40 students. The eight teachers who taught these students had between two to ten years of teaching experience in their disciplinary subjects of Biology, Chemistry or Physics. The study was first approved by the Institutional Review Board of a local university, following which approval was obtained from the Ministry of Education for data collection at the school. The students were then given a letter to obtain consensus from their parents as they were below 21 years old, out of which 227 parents gave the consensus for their children's participation. Following parental consent, student consent was sought. A total of 89 (39.20%) males and 138 female students (60.80%) eventually consented to participate in the study.

Instrumentation, data collection and analysis

Data was collected to assess each level of evaluation as described by the Kirkpatrick and Kirkpatrick (2006) model as follows:

Level 1 – Reaction

Students' perceptions of 21st century learning was assessed through implementation of Chai et al.'s (2015) survey which examined students' perception of 21st century learning through the dimensions of self-directed learning (SDL), collaborative learning (CoL), critical thinking(CriT), creative thinking(CreT), authentic problem-solving (APS), knowledge creation efficacy(KCE), and meaningful use of ICT (ICT). This survey was chosen as it has been validated with Singapore students. A pre-study survey was administered to the students at the beginning of their Secondary 2 school year to assess their perceptions of 21st century learning dimensions in their Secondary 1 Science class. A post-study survey was administered to students at the end of the Secondary 2 school year to assess their perceptions of 21st century learning dimensions through the Integrated Science module.

As the original survey was implemented with primary school students and was not subject-specific, the questions were adapted in this study by changing the question stems e.g., "In my Secondary 1 Science class, I …" and "In the Integrated Science class, I …". The survey implemented comprised 33 Likert-scale questions where students' agreement or disagreement with different aspects of 21st century learning dimensions where assessed as '1' – Strongly disagree, '2" – Disagree, '3' – Neutral, '4' – Agree, '5' – Strongly agree. There were also open-ended questions asking students about the activities during the lesson that they enjoyed and how the programme design could be improved.

A total of 227 pre and post-study surveys were received, constituting a response rate of 58.96%. Of the original 385 students, there were 115 students who opted out from the study as their parents did not give permission for them to participate in the study. The responses of another 43 students were omitted from analysis as 36 of them did not complete the post-study survey and seven submitted incomplete post-study surveys. Adequate Cronbach alpha reliabilities were obtained for all constructs of the pre-study survey (SDL: 0.89, CoL: 0.83, CriT: 0.80, CreT:0.88, APS: 0.86, KCE: 0.85, ICT: 0.91). For the post-study survey, an SDL item, "In the Integrated Science class, I make plans for how I will study" was removed to improve the reliability of the SDL scale. Adequate reliabilities were then obtained for all the constructs (SDL: 0.89, CoL: 0.89, CriT:0.80, CreT: 0.87, APS: 0.82, KCE: 0.82, ICT: 0.91). Confirmatory factor analysis using the pre-course survey established adequate model fit ($\times^2$ = 856.86, df =

474, ×2/df = 1.81 ($p<0.00$), AGFI = 0.79, TLI = 0.87, CFI = 0.88, RMSEA = 0.072 (LO 0.066, HI 0.078), SRMR = 0.060).

Research question 1 was answered with a paired-sample t-test to examine how students' perceptions of the 21st century learning dimensions differed between their Secondary 1 science classes and their experiences from the Integrated Science module. Themes emerging from content analysis of students' responses to the open-ended question related to what they enjoyed about their Science lessons from the pre and post study surveys were also examined to triangulate the survey results.

Level 2 - Learning

The relationships between students' perceptions of 21st century learning and their exam results through multiple linear regression between the post-study ratings of 21st century learning dimensions with students' results from their Secondary 2 end-of-year examination. The students' scores on questions from the end-of-year examination that assessed the students about their content knowledge of all the topics that they have learnt from the Integrated Science module were selected for analysis. Questions types included multiple choice, structured questions and long questions. This was used to answer research question 2.

Level 3 – Transfer of behaviour

In-depth interviews were conducted with nine students from three classes who were taught by teachers with varying teaching experiences. The first teacher had taught Integrated Science for at least six years, the second teachers had four years of teaching experience whereas the last teacher had taught the module for only two years. Each teacher nominated three students of low, middle and high ability respectively from their class. The selection of subjects allowed feedback to be gathered about learning transfer to encompass insights from a range of classes, teachers, and students. A semi-structured interview was conducted where students belonging to the same class were interviewed as a focus group. Students' responses were audio-recorded and each session lasted between 30-40 minutes. To answer research question 3, the interviews were transcribed and coded for emerging themes using phrases as a unit of analysis. To ensure consistency of the coding, a second rater coded a random selection of the transcript to an inter-rater agreement of 80%. The rest of the transcripts were then coded by the first author.

Findings

Research question 1 - Students' perception of 21st century learning experiences

The development of students' perceptions of various constructs of 21st century learning from the lower science curriculum is shown in Table 2.

Table 2. Paired sample t-test

21st century learning dimension	Programme	M	SD	t	d
Self-directed learning (SDL)	Sec 1	3.82	0.62	2.34*	0.16
	Sec 2 Integrated Science	3.92	0.66		
Collaborative learning (CoL)	Sec 1	3.82	0.64	-0.09	0.00
	Sec 2 Integrated Science	3.82	0.70		
Critical thinking (CriT)	Sec 1	3.96	0.63	-0.62	0.05
	Sec 2 Integrated Science	3.93	0.62		
Creative thinking (CreT)	Sec 1	3.66	0.69	0.79	0.06
	Sec 2 Integrated Science	3.62	0.69		
Authentic problem-solving (APS)	Sec 1	3.68	0.68	5.45**	0.40
	Sec 2 Integrated Science	3.93	0.58		
Knowledge creation (KCE)	Sec 1	3.72	0.61	0.19	0.00
	Sec 2 Integrated Science	3.72	0.61		
Meaningful learning with ICT (ICT)	Sec 1	3.26	0.88	0.28	0.02
	Sec 2 Integrated Science	3.28	0.88		

Note. N = 227, *p<0.05 ** P<0.001

Analysis of results from Table 2 show that the students generally agreed that they experienced the different 21st century learning dimensions through their Secondary 1 science lessons. This can be seen from the means for the dimensions of SDL, CoL, CriT, CreT, APS, and KCE that were all above 3.6 out of a five-point scale. The paired sample t-tests show that students' positive perceptions of 21st century learning was maintained throughout their Integrated Science module during Secondary 2. The mean scores for the dimensions of CoL, CriT, CreT, and KCE were maintained. However, the Integrated Science module deepened students' perceived engagement in SDL and APS. Significant positive differences were observed in these two dimensions with a close to moderate effect size noted for APS.

Table 3 shows an analysis of students' open-ended responses about the activities they enjoyed in their learning experiences for Science. Students' perceptions of the Secondary 1 and Secondary 2 Integrated Science module differed greatly. For the Secondary 1 curriculum, majority of the student comments show that they enjoyed learning through collaborative work and developing understanding of science concepts through hands-on laboratory experiments. While these aspects were also appreciated in students' perceptions of their Secondary 2 Integrated Science module, the proportion of comments appreciating opportunities to solve real-world problems and learning from peers through collaborative learning increased. Several new dimensions also emerged, including enjoyment of exploring science in an authentic environment through a trip to the wetlands, gaining new and deeper knowledge about Science, learning from viewing and making videos about Science, as well as having fun and being engaged in the learning experience. From the themes that emerged, it can be seen that 21st century dimensions of CriT, KCE, and APS were synthesized within opportunities for students to learn by doing from experiments, doing scientific inquiry and solving real-world problems. KCE can also emerge through meaningful learning with ICT when students were given opportunities to create videos to express their understanding of Science. Such kinds of activities were perceived by students to be fun and engaging, resulting in the emergence of the theme of motivation from students' open-ended comments.

Table 3. What students enjoy during Science lessons

Categories	Secondary 1 Science curriculum (Students who provided response = 106)		Secondary 2 Integrated Science module (Students who provided response = 223)	
	Coded units	%	Coded units	%
Learning by doing				
1. Develop understanding of science concepts through hands- on laboratory experiments (CriT/KCE)	79	84.04	42	9.93
2. Better understanding from applying scientific inquiry process (KCE)	-	-	3	0.71
3. Solving real-world problems (CreT/APS)	1	1.06	54	12.77
4. Exploring science from trip to wetlands (APS)	-	-	53	12.53
Collaborative Learning (CoL)				
1. Learning from peers through collaborative work	14	14.89	100	23.64
Learning science content knowledge				
1. Gain new knowledge about Science	-	-	42	9.93
2. Gain deeper understanding of science concepts	-	-	15	3.55
3. Facilitates recall of scientific concepts	-	-	1	0.24
Meaningful learning with ICT (ICT)				
1. Learning from videos about science	-	-	7	1.65
2. Learning from making own videos about science (KCE)	-	-	2	0.47
Motivation				
1. Fun and engagement	-	-	102	24.11
Self-directed learning (SDL)				
1. Autonomy to choose own project	-	-	2	0.47
	94	100.00	423	100.00

Note. N= 227

Research question 2 - Students' learning

The Pearson's correlations between students' exam scores and their post-study ratings of 21st century learning dimensions showed significant positive correlations between Exam scores and CriT_P, APS_P, and SDL_P (see Table 4). Table 4 also shows that the strength of correlations among 21st century learning dimensions were stronger than their correlations with exam scores. CriT_P had large positive correlations with CreT_P, APS_P, and KCE_P. Similar relationships were observed between CreT_P and KCE_P; and well as between APS_P and KCE_P. The correlations among the other 21st century learning dimensions were positive but moderate.

Table 4. Pearson's correlation among exam and 21st century learning dimensions

	Exam	ICT_P	CoL_P	CriT_P	CreT_P	APS_P	KCE_P	SDL_P
Exam	1	-.00	.05	.24**	.12	.14*	.13*	.19**
N	224	224	224	224	224	224	224	224
ICT_P		1	.44**	.43**	.48**	.41**	.48**	.40**
N		227	227	227	227	227	227	227
CoL_P			1	.45**	.57**	.43**	.45**	.48**
N			227	227	227	227	227	227
CriT_P				1	.64**	.60**	.62**	.63**
N				227	227	227	227	227
CreT_P					1	.59**	.69**	.50**
N					227	227	227	227
APS_P						1	.65**	.46**
N						227	227	227
KCE_P							1	.50**
N							227	227
SDL_P								1
N								227

Note. N=224 as three students who completed the post-study survey were absent for the final exam. ** p<0.01, * p<0.05

As some significant correlations were indicated through the correlation analysis, a multiple linear regression was carried out. Multiple linear regression using the Enter method was statistically significant ($F(7,216)= 2,70$, $p<0.05$), with an R^2 of 0.08. From Table 5, it can be seen that of the 21st century learning dimensions, only Cri_P was a key predictor of exam results, contributing positively to it. The other learning dimensions were not key predictors.

Table 5. Multiple linear regression model

Model	B	Std. Error	Beta	t	Sig.
(Constant)	24.40	3.49		7.00	**
ICT_P	-1.02	.61	-.13	-1.67	n.s.
COL_P	-.513	.801	-.05	-.64	n.s.
CriT_P	2.59	1.06	.25	2.44	*
CreT_P	-.22	1.00	-.02	-.22	n.s.
APS_P	.21	1.05	.02	.20	n.s.
KCE_P	.24	1.12	.02	.21	n.s.
SDL_P	1.14	.93	.11	1.23	n.s.

Note. **p<0.001, p<0.05, n.s.=not significant

Research question 3 – Transfer of learning

Table 6 shows the kinds of skills that the nine students interviewed felt they could transfer from the Integrated Science module to their other academic subjects.

Table 6. Transfer of skills from Integrated Science module

Knowledge and skills	Coded units	%	Example
Information analysis skills	9	34.62%	[When] we are given very long text we have to pick up more important information from the different text ... [we] can use those type of skills … during English.
ICT skills	7	26.92%	[We can use video production skills] for English Literature, [when] we need to put different video clips together for our final project.
Presentation skills	7	26.92%	And recently, we had English and Chinese Oral … you probably wouldn't feel so worried because you are equipped with the skills [for presentation].
Time management skills	3	11.54%	[When] we do other projects, we will not [be] so last minute [so that we can] finish on time
	26	100.00	

It can be seen that the most-often cited skill that students transferred from the Integrated Science module to their other academic subjects was information analysis skills which involved the use of critical thinking to analyse, identify, and synthesize information. ICT skills, presentation skills, and time management skills relate to what is considered as productive skills in 21st century competency frameworks (e.g. P21, 2007). Students perceived that through authentic inquiry-based projects in the Integrated Science module, they were able to develop and transfer such kinds of general "life-skills" to support learning of their other academic subjects.

Discussion

Through an evaluation of lower secondary school students' reactions and learning from a lower secondary science curriculum, this study found that by the end of Secondary 1, the learning activities generally helped students to develop a fairly high level of confidence in the 21st century learning dimensions of SDL, CoL, CriT, CreT, APS, KCE, and ICT. The students' experience with the inquiry-based Integrated Science module in Secondary 2 further developed their confidence in SDL and APS. Correspondingly, CriT contributed positively to the prediction of students' end-of-year results whereas students also shared evidence of themselves developing skills that could be transferred and used in learning their other academic subjects. The findings of the study provide the following insights for the design of 21st century learning in schools:

Pedagogical elements supporting 21st century learning in science education

The pedagogies adopted in designing the school's science programme supported the ethos of the Singapore Ministry of Education's Lower Secondary Science education (Ministry of Education, 2012) which emphasized inquiry-based learning and creative problem solving. The results in Table 2 show that the practical sessions, group discussions, workshops and poster design projects employed in Secondary 1 enabled students to be confident in CoL, CriT, CreT and KCE, so much so that a ceiling effect was observed in the pre-study ratings. It was upon this foundation that students were well prepared to undertake the Integrated Science module in Secondary 2. The findings show that the deliverables in the Integrated Science module such as report proposal, investigative project and project presentation were successful in enhancing students' confidence in SDL and APS as indicated by the t-test results in Table 2. Particularly, the report proposal and investigative project provided platforms for students to plan and conduct independent research in teams and find possible solutions to solve real-world problems that are related to environmental protection. Therefore, the results indicate that this progressive approach to scaffolding students' engagement in inquiry-based problem-solving to be a pedagogical strategy that could be considered when designing 21st century learning. The results from Table 3 indicate that even though students did not perceive enhanced CoL, CriT, or KCE between the pre and post study survey, the hands-on and collaborative components of learning were perceived to be elements of the pedagogy that they greatly enjoyed.

Despite the positive ratings of students for 21st century learning dimensions, only CriT positively predicted exam results and this factor explained 8% of the regression model variance. It appeared that the exam had a good proportion of higher order thinking questions that required students to engage in critical thinking. Yet, the individual and content-focused mode of examinations meant that there was little opportunities to engage skills such as CoL, APS, SDL, and KCE that were developed through students' learning experiences. Dede (2007) argued that 21st century competencies tend to be inter-related. The strong correlations found in this study among CriT, CreT, APS, and KCE attest to this point. Therefore, a traditional paper-and-pencil exam may not adequately capture the effects of the learning results attained through 21st century learning experiences. Alternative assessment modes may need to be considered.

Designing for transfer

The interview of students supports Voogt et al.'s (2013) proposition that 21st century competencies are a set of portable skills. In this study, the students transferred critical thinking skills for information analysis as well as improved confidence in productive life-skills related to technology, presentation, and time management. Such kinds of skills, when practiced systematically across 21st century learning experiences in school-based curriculums can have immense impact for preparing students for the realities of the future workplace. Despite this, the students interviewed did not mention the 21st century competencies related to thinking skills such as creative problem-solving and metacognition. This could be because students might have related these more strongly with their subject-based learning and perceived fewer opportunities for transfer. Some methods to deepen the transfer of learning for these thinking skills would be giving more examples to students on how they could apply the thinking process to other situations or subjects, and to work with other discipline subjects on combined project assessment; for example with the mathematics department on readings collection and data presentation from experiment. The school could also provide opportunities for students to participate in external science research competitions so that they could apply what they have learnt through the investigative projects. -

Improving the Integrated Science programme

An element of the pedagogy that did not appear to have emerged strongly was students' perception of meaningful use of ICT. While the ratings for ICT as per Table 2 were still fairly high, it nevertheless had the lowest rating among the 21st century learning dimensions. Crippen and Archambault (2012) suggested that ICT could be used in ways that scaffold inquiry for STEM education. As students in the study expressed interest in collaborative work, a starting point would be for teachers to explore how some videos of real-world problems they are currently showing as class examples could be restructured into collaborative problem-solving experiences, supported with ICT collaborative tools. Teachers could also strengthen their use of ICT tools by analysing the difference Science activity types recommended by Blanchard, Harris, and Hofer (2011). This comprises ready pieces of technological pedagogical content knowledge (TPACK) (Harris, Mishra, & Koehler, 2009) that are developed to guide the integration of ICT into Science.

From Table 3, it appeared that students valued learning by doing as well as authentic learning. Examples of improvements that could be carried out for future runs of the programme would be more experiments designed for the different topics to increase students' hands on experience, more outdoor learning trips so that students could have authentic learning and at the same time engage in collaborative investigations for real world problems. Students from the same class could go to different outdoor locations and produce digital artifacts of their learning for sharing with peers. This could further enhance the integration of ICT for meaningful learning in the module.

Limitations and future research

There are several limitations in this study that could constitute areas for future improvement and research. Firstly, as the survey was administered only after permission were obtained from both parents and students, the pre survey could only be conducted after students began their Secondary 2 school year. Thus, for future research, the pre-study survey could be conducted at the end of students' Secondary 1 school year. This might provide more accurate recall of students' Science learning experience during Secondary 1. Secondly, as students were awarded a group score for their collaborative inquiry project completed during the Integrated Science module, their project score may not be an indication of individual performance for inquiry. Therefore, these results were not used for regression analysis. As a result, the relationships between student learning and 21st century dimensions could only be examined with their end-of-year examination scores. In future studies, students could be asked to perform an individual inquiry task as an additional assessment component; and the regression outcomes compared to that from the paper-and-pencil test. This can provide more insight about how 21st century learning dimensions may support different kinds of assessment modes. Thirdly, the study was conducted with lower secondary students for Science. This study could be replicated with different subjects taken by students of different K-12 levels. In this way, more comprehensive understanding of students' successes and challenges with 21st century learning could be achieved. Finally, data related to students' inquiry process was not analysed as the aim of the study was to examine learning outcomes as per the three levels of Kirkpatrick and Kirkpatrick's (2006) model which comprised of reaction, learning, and transfer. As the quality of inquiry processes could influence student learning outcomes and how they developed 21st century skills, it is suggested that this area could be further investigated in future studies.

Conclusion

In this study, we examined the effects of 21st century learning experiences on students after going through the school's Integrated Science module using the Kirkpatrick and Kirkpatrick (2006) evaluation model. Even though the study showed evidences of positive student experiences and outcomes, the inter-relationships among various 21st century learning dimensions and their effects on different kinds of student assessments continue to be areas of critical importance to educators. These various aspects need to be given deeper analysis as schools seek to implement 21st century learning with their students.

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