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1. Quantifying the Effects of Personalized Assessment Tasks in Secondary Science Teaching

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ABSTRACT

Tensions between the perception and reality of scientific practice have produced significant problems, including the fact that high proportions of students do not view science as a creative endeavour. The resultant, systemic devaluation of science has significant implications for scientific research, and science education. To maintain and develop a capacity for quality intellectual output requires development and implementation of learning programs that provide opportunities for individuals at all levels of education and practice to: acquire a high level of core content knowledge; practice application of that knowledge across a gradient of difficulty; and be challenged to integrate their knowledge of science with knowledge of other fields to pursue and solve problems with personal relevance. This chapter examines the impact of teaching and learning strategies designed to foster personal engagement and creative thinking, without compromising foundation knowledge, in a Senior (Year 11 and 12) Chemistry program. Performance of students (four cohorts aged 15-18 years; n = 79) was assessed relative to a quantitative index of academic capacity, generated through factorial analysis of data from other subjects. Results indicate that the development of teaching, learning and assessment methods/instruments that challenge students to connect foundation knowledge to problems with personal relevance not only enhances general, affective factors but also supports realization of creative potential.

INTRODUCTION

Throughout the course of human history, social and cultural change has always been effected by, and reflected in, changes to systems of education. Current interest in teaching for creativity within the field of science can be traced to a pervading belief that contemporary individuals and nations are living through a period of transition from old-world forms of work based on physical labour, to more intellectually intense, knowledge-based modes of operation.

This perception of a rapidly changing world, and a consequent need for new education and training paradigms (Calhoun, 2009; Coates & Goedegebuure, 2012; Douglass, Thomson, & Zhao, 2012; Frodeman, 2011; Hayden & Lam, 2007; Kitagawa & Oba, 2010; Lam, 2010; Obamba & Mwema, 2009; Oprescu, 2012; Ramoniene & Lanskoronskis, 2011; Whitchurch, 2012), emerges from interplay between personal and political conceptualizations of what it is, and what it means, to be creative and can be interpreted through reference to four distinct, but overlapping, discourses of creativity (Schmidt, 2011a, 2011b):

- *A developmental discourse*, which assumes that all individuals are capable of a degree of creativity that is commensurate with their level of cognitive development.
- *A psychometric discourse*, which is concerned with the interaction of internal and external traits, characteristics and events that can be measured, manipulated or exploited to predict, calculate or control creative output.
- *A sociocultural discourse,* which is concerned with the social, cultural and economic factors that stimulate, refine and sustain interest in creativity in the first instance; and the ways that these might generate or erode social and economic inequity at the level of individuals, communities and nations.
- *An entrepreneurial discourse*, which is concerned almost exclusively with the economic and commercial value of creative products.

Rhetoric surrounding reforms to science education tends to focus on reversing a trend of declining enrolments in science subjects, the need to generate a technologically competent, scientifically literate workforce and the economic, environmental and social benefits associated with initiation and development of novel technologies and industries (Harris, 2012; Kessels, Rau, & Hannover, 2006; McWilliam, Poronnik, & Taylor, 2008; Universities Australia, 2012). This is consistent with sociocultural and entrepreneurial discourses, but lack of connectivity to concrete teaching and learning practices frustrates educators (Newton & Newton, 2009; Settlage, 2007) and failure to recognize the importance of moral and ethical frameworks in academic and educational settings poses a significant threat to quality and originality of intellectual output, particularly at the postgraduate and professional levels (Clegg, 2008; Schmidt, 2011a).

Explicit attention to pedagogy is a relatively new phenomenon in the tertiary education sector (Krause, 2012; Shay, 2012), but primary and secondary educators have a long history of translating developmental and psychometric theory to teaching and learning practice. In science education, it is widely recognized that development of key skills and knowledge is facilitated by well-planned and skilfully implemented learning programs that incorporate inquiry and argumentation activities (Barrow, 2006, 2010; Nadelson, 2009; Nancy Butler, Hee-Sun, & Scott, 2003; Nowak, 2007; Taylor, Jones, Broadwell, & Oppewal, 2008; William, 2005; Windschitl, Thompson, & Braaten, 2008).

To deploy inquiry methods in ways that develop creativity, it has been suggested (Schmidt, 2010, 2011a) that learning programs should incorporate opportunities for students at all levels to: 1) Acquire a high level of domain-specific knowledge; 2) Practice application of that knowledge across a gradient of difficulty and ; 3) Link knowledge of science to knowledge of other fields in order to solve problems with personal relevance.

That the initial acquisition of domain-specific knowledge is highly dependent on fundamental (e.g. language, literacy and numeracy) skills is both consistent with a developmental approach and supported by empirical evidence. Prior academic performance is a significant predictor of achievement in secondary (Hogrebe & Tate, 2010) and tertiary science students (Universities Australia, 2012) and the ability to generate creative output is linked to above-average cognitive development/ability (Runco & Chand, 1995; Runco & Okuda, 1988; Sweller, 2009; Wu & Chiou, 2008). There is however, also strong evidence that those who go beyond knowledge accumulation and generate creative output display complex, and highly variable, combinations of social, psychological and intellectual characteristics (Boden, 2001; Christine & Glenn, 2007; Miller, 2000; Simonton, 2003a).

Studies of gifted and talented primary students highlight the importance of factors other than foundation skills. Dispositional elements such as emotional intelligence (Agnoli et al., 2012) and willingness to engage with, and respond flexibly to, challenge (Klavir & Gorodetsky, 2011) are strongly correlated with performance on academic tasks, but can be highly developed in students who would not be recognized as gifted in tests that examine academic skills alone (Klavir & Gorodetsky, 2011; Tzuriel, Bengio, & Kashy-Rosenbaum, 2011).

The significance of emotional-motivational factors also appears to increase as students progress through the education system. Studies of Italian students in the latter years of secondary schooling show that grade point average is strongly influenced by the extent to which students are able to manage emotions (DiFabio & Palazzeschi, 2009). Further, a study of Spanish students has shown that exposure to high teacher expectations and a positive learning environment in secondary school is one of the most powerful predictors of successful transition to post-compulsory education (Martín, Martínez-Arias, Marches, & Pérez, 2008).

An individual's early experience of schooling is therefore significant not only in terms of enabling or limiting access to further education and development opportunities and determining socioeconomic status, but also in shaping psychosocial orientations to self and other. Individuals' attitudes, beliefs and perceptions in relation to their own academic ability are strongly correlated with scholastic performance (Areepattamannil & Freeman, 2008; Griffin, Chavous, Cogburn, Branch, & Sellers, 2012) and studies of tertiary students from disadvantaged and/or non-dominant backgrounds show that interventions focused on resolution of intrapersonal tensions are more likely to result in program completion than those focused on content alone (Griffin et al., 2012; Reinheimer & McKenzie, 2011). Establishing and maintaining a positive, constructive orientation to learning may even be a particular requirement for success in science, as specific measures of emotional intelligence appear to be elevated in BSc students, when compared to their BA counterparts (Aslam & Ahmad, 2010).

To design and implement education programs that support and facilitate conversion of creative potential to creative output then, educators must recognize the need for a more holistic approach to teaching and learning. Awareness of this is a driving force behind calls for greater personalization of learning experiences (Milliband, 2004; Verpoorten, Renson, Westera, & Specht, 2009). In a tertiary context, personalization has become synonymous with use of ICT (e.g. Beres, Magyar, & Turcsanyi-Szabo, 2012; Peter, Bacon, & Dastbaz, 2010; Sampson & Karagianidis, 2002; Tu, Sujo-Montes, Yen, Chan, & Blocher, 2012). In primary and secondary settings however, personalization is more accurately aligned with the concept of differentiation.

In recognizing that individuals within any given cohort of same-age students will differ in their life circumstances, past experiences and readiness to learn (Tomlinson, 2000), proponents of differentiation advocate a dynamic, flexible approach to teaching and learning where teachers engage in on going adjustment of content, process and products to ensure that all students are challenged to work slightly above what they can do independently (Rock, Gregg, Ellis, & Gable, 2008; Tomlinson, 1999).

In primary schools, attention to personal needs through small group instruction is up to four times as effective as undifferentiated, whole-class instruction (Connor et al., 2010). For educators working with students at higher levels of education however, attempts to differentiate must overcome significant challenges. The first of these is low teacher-student ratios. In tertiary settings, these may realistically lie in the vicinity of one lecturer to several hundred students, which is one likely reason why ICT-mediated instruction has become so prevalent.

At a secondary level, there is greater recognition of the need for interpersonal connection and teacher-student ratios are more favourable. In this setting however, the challenge is not simply providing pathways from generic language and literacy skills to domain-specific proficiency, but doing so in a way that navigates sociocultural terrain characterized by challenges associated with access to material resources, relationships, identity, power and control, cultural adherence, social justice and personal cohesion (Fondacaro et al., 2006; Garbrecht, 2006).

The aim of this study is to investigate the impact of personalization on student learning in senior secondary students undertaking a two-year, tertiary preparation course in Chemistry. As in other countries, Australian secondary education is in a period of transition to national curriculum, but the study was undertaken in an environment where course content remained the mandate of The State of Queensland. The syllabus stipulates a requirement for context-based units, defined as provision of opportunities for students to learn "…in circumstances that are relevant and interesting to them…" with knowledge and understanding "…developed, consolidated and refined in, about and through the context." (p.45) (Queensland Studies Authority, 2007), but teachers in each school retain responsibility for writing and marking assessment tasks. To ensure that these comply with content and delivery requirements, folios of student work are reviewed by regional panels of experienced teachers at the end of the first (moderation) and second (verification) years of study (Queensland Studies Authority, 2007). The system is not without fault, but the approach is consistent with findings from targeted studies of high-performing schools and educators, which show that locally developed solutions to local issues and problems are a hallmark of quality education (Hargreaves & Shirley, 2009).

Scepticism about the utility of more generic, national testing regimes arises from evidence that test scores often map more accurately to sociocultural and socioeconomic status than to student ability (Cheng, Fox, & Zheng, 2007; Grodsky, Warren, & Felts, 2008; Hogrebe & Tate, 2010; Rubin, 2008). Despite significant correlations between performance on national and classroom tests, a majority of teachers believe that classroom assessment provides superior insights into student learning (Leighton, Gokiert, Cor, & Heffernan, 2010; McBride, Ysseldyke, Milone, & Stickney, 2010). Kyriakides (2004) has argued that one of the key reasons for this is that distancing classroom teachers from assessment processes constrains connectivity with interpersonal knowledge of the individuals within the classroom.

The core aim of this study was to examine the contribution that interpersonal knowledge makes to student learning. In particular, the aim was to determine whether personalization of assessment tasks delivers quantifiable improvements in student performance that are independent of general academic ability.

DATA COLLECTION AND ANALYSIS

The study population consisted of 79 (39 females, 40 males) 15 to 18 year-old Chemistry students from four cohorts (graduating years 2010, 2011, 2012 and 2013) attending a government-funded, secondary school in Queensland, Australia.

To qualify for tertiary entrance in the Queensland system, students must complete four semesters (two years) of study in a minimum of five authority subjects that contribute to a tertiary ranking (Overall Position or OP) score. Chemistry is an authority subject and most students in the study were enrolled in five or six authority subjects (Chemistry plus four or five others) in total (Table 1). A small number (n=3) however, were electing not to apply for university and were also undertaking studies in non-authority subjects such as English Communication and Pre-Vocational Mathematics. As these students had all transferred after achieving non-pass grades in an authority subject (English or Mathematics A), further analysis used only results from the authority subject (to avoid distortion).

Complete (four semester) data were available for 26 students (2010 and 2011 cohorts). Less than four semesters of data were available for the remaining 53 students, because they were partway through the program of study (n = 29), transferred to other subjects (n = 21) or transferred to or from another school (n = 3).

Analysis was therefore based on average-to-date (fullest and latest) data for 53 (67%) students (2012 and 2013 cohorts) and complete (four semester) data for the remaining 26 (33%) (2010 and 2011 cohorts).

All statistical analyses were undertaken using PASW® 18.0 software (SPSS Inc. 2009).

Table1: Summary of Academic Achievement Across Subjects
**Average, skewness and kurtosis statistics were not calculated for Geography (n = 1).*

Subject	***n***	***Mean ± S.E.***	***Skewness ± S.E.***	***Kurtosis ± S.E.***
English	75	3.52 ± 0.10	-0.12 ± 0.27	-0.52 ± 0.55
Mathematics A	20	3.38 ± 0.23	0.37 ± 0.51	-0.87 ± 0.99
Mathematics B	63	3.19 ± 0.14	0.01 ± 0.30	-0.57 ± 0.60
Mathematics C	16	3.69 ± 0.26	-0.11 ± 0.56	-1.09 ± 1.09
Physics	32	3.45 ± 0.18	0.06 ± 0.41	-1.00 ± 0.81
Biology	40	3.43 ± 0.12	0.17 ± 0.37	-0.11 ± 0.73
Legal Studies	5	3.00 ± 0.00		
History Ancient Modern	 9 8	3.74 ± 0.18	-0.33 ± 0.52	-0.22 ± 1.01
Geography	1	3.00*		
Health & Physical Education	8	4.12 ± 0.23	-0.07 ± 0.75	0.74 ± 1.48
ICT/Business	13	3.38 ± 0.23	-0.28 ± 0.50	0.11 ± 0.97
Language Japanese German	 10 11	4.33 ± 0.14	0.57 ± 0.50	-0.26 ± 0.97
Art	7	3.71 ± 0.42	-0.25 ± 0.79	-0.94 ± 1.59
Graphics	6	4.67 ± 0.21	-0.97 ± 0.85	-1.88 ± 1.74
Technology Studies	11	3.95 ± 0.26	-1.17 ± 0.66	2.12 ± 1.28
Music	11	4.09 ± 0.24	0.01 ± 0.66	-1.57 ± 1.28

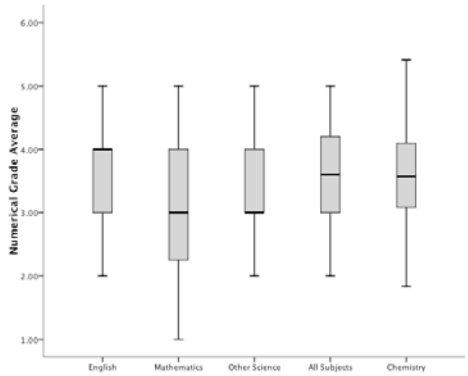


Figure 1: Academic Performance Across Subjects
Deviations from normal distribution were detected for English and Other Science (Physics and/or Biology). Chemistry grades were not significantly different to grades in other subjects.

Academic Achievement: To generate comparable measures of achievement for each cohort, A to E grades were converted to numerical variables (A = 5, B = 4, C = 3, D = 2, E = 1) and averaged across subject groups (Fig. 1). Single-subject averages were calculated for English, Mathematics and Other Sciences (Physics and Biology), but due to relatively small numbers of students in other subjects (Table 1), a single All Subject Average was considered more viable than separation into discipline groups (e.g. combining History and Art to give an index of achievement in the Humanities).

This produced four new variables summarizing achievement in English, Mathematics, Other Sciences (Biology and Chemistry) and All Subjects. Deviations from normal distribution were detected for the English (S-W statistic = 0.889, df = 75, p <0.001) and Other Science (S-W statistic = 0.919, df = 64, p <0.001) variables (Fig. 1), but as the dataset was transformed prior to further analysis (see below), this was not problematic.

Variable Reduction: Subject-specific data were converted to a more general index of academic capacity through principal components analysis. Given the high inter-correlation of grades across subjects, and an increase in sample size when the dataset was not limited to students studying an additional science (Physics or Biology), only the English, Mathematics and All Subjects indices were subjected to further analysis.

The data reduction procedure used the matrix of covariance, with pairwise elimination of cases missing data for one or more of the original subject-specific indices (n = 74) and varimax rotation. This analysis generated a single variance component with an eigenvalue greater than one (2.492), which explained 83% of the covariance. Subject-specific loadings were high for all three of the subject specific indices (English = 0.831; Mathematics = 0.937; All Subjects = 0.962). Individual scores were saved and used as an Academic Performance Index (API) in further analysis.

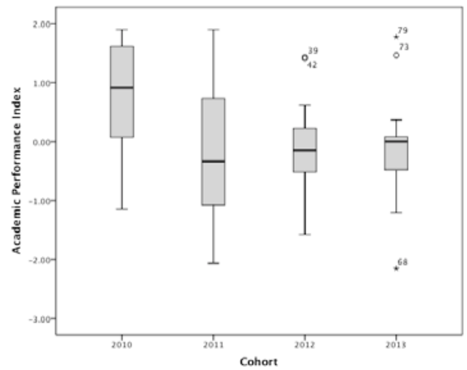


Figure 2: Academic Performance Index across Cohorts

Some variation was evident across cohorts (Fig. 2), but standardized residuals for the entire data set (2010 n = 12; 2011 n = 23; 2012 n = 22; 2013 n = 17) were normally distributed (Shapiro-Wilk stat. = 0.978, df = 74; p = 0.234; Skewness = 0.014 ± 0.279; Kurtosis = -0.459 ± 0.552).

Chemistry Data: A preliminary ANOVA indicated that achievement in Chemistry was not significantly different from achievement in other subjects (Fig. 1). Variation within groups was not significantly different to variation between groups for English (F = 1.449; df = 71, 2; p = 0.495), Mathematics (F = 2.098; df = 72, 2; p = 0.377), Other Science (F = 1.402 df = 61, 1; p = 0.598) or All Subjects (F = 3.821; df = 74, 2; p = 0.230) (Fig. 4).

Performance in Chemistry varied across cohorts (Fig. 2), but data were normally distributed when all cohorts were combined (S-W stat. = 0.981, df = 79, p = 0.271; skewness = 0.181 ± 0.271; kurtosis = -0.235 ± 0.535).

To capture maximum information regarding the impact of personalized assessment tasks, a range of Chemistry-specific achievement indices were generated, based on three mandated (syllabus) dimensions designated Knowledge and Conceptual Understanding (KCU), Investigative Processes (IP) and Evaluating and Concluding (EC).

According to the Senior Chemistry Syllabus (QSA, 2007):

– The KCU mark indicates the extent to which students are able to recall and interpret concepts, theories and principles; describe and explain processes and phenomena; and link and apply algorithms, concepts, theories and schema.

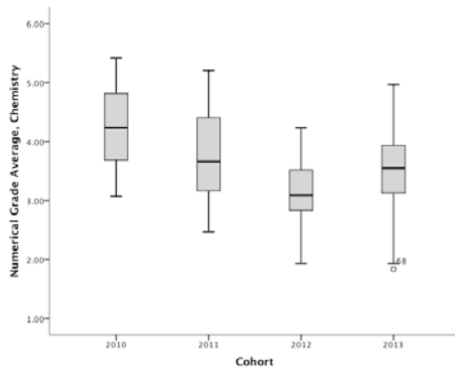


Figure 3: Chemistry Grades across Cohorts

– The IP mark indicates the extent to which students can conduct and appraise research tasks; operate chemical equipment and technology; and use primary and secondary data.
– The EC mark indicates the extent to which a student can determine, analyze and evaluate chemical interrelationships; predict outcomes and justify conclusions and recommendations; and communicate using a range of formats.

In addition to calculations of separate KCU, IP and EC averages, an overall level of achievement was generated by averaging all KCU, IP and EC grades.

To allow discrimination within levels of achievement, conversion of grades to numerical variables (A = 5, B = 4, C = 3, D = 2, E = 1) included plus and minus levels of achievement as decimal components. Plus grades were designated *X*.9 (e.g. B^+ = 4.9), mid-range grades were designated *X*.5 (e.g. C = 3.5) and minus grades were designated *X*.1 (e.g. A^- = 5.1).

Classification of Assessment Tasks: Categorization of assessment tasks was based on three instrument types recognized by the Queensland Chemistry syllabus (QSA, 2007):

– Supervised Assessment (SA): Instruments administered under supervised conditions to ensure authenticity of student work that may include short items, practical exercises, paragraph responses and responses to seen or unseen stimulus materials
– Extended Response Task (ERT): Instruments developed in response to a chemical question, circumstance or issues that are essentially non-experimental, but may draw on primary experimental data.
– Extended Experimental Investigation (EEI): Instruments developed to investigate a hypothesis or answer practical research questions through laboratory or field based, self-directed experimentation and reporting.

Within each of these categories, the degree of personalization was assigned relative to the extent of student choice.

Tasks with low personalization (Non-Personalized) included six standard written exams (SA), where all students were required to generate responses to an identical set of multiple choice/short answer/medium length answer questions with a single opportunity to choose from one of two longer, complex questions at the end of the paper (Table 2).

Tasks with a medium level of personalization (Medium Personalization) included two EEIs and one SA (Table 2). These were classified as having a medium level of personalization because the overall problem to be solved required development/application of similar methods and techniques for all students and, although all individuals were required to produce individual outputs, a substantial degree of collaboration and overlap was possible in generation of solutions.

Tasks with a high degree of personalization (High Personalization) included one SA and two ERTs (Table 2). Like the EEIs, these tasks required all students to solve problems and produce outputs that were conceptually similar, but a key point of difference was that high-personalization meant the system to be studied was self-determined; although teacher assistance was provided and students who had difficulty choosing a system were given more substantial direction.

Using these groupings, eight Chemistry-specific achievement indices were generated by averaging grades (Overall, KCU, IP and EC) across personalized (P) and non-personalized (NP) tasks. These formed the central focus of the analysis, but additional sets of indices were later generated for medium and high personalization tasks.

Table 2: Summary of Assessment Tasks

Year Level	*Task No.*	*Type*	*Description of Task*		*Chemical Content*	*Product(s)*	*Personalization*
11	1a	SA	Practical Exam 3 x 70 minute lessons	Students provided with a set of reagents and relevant background information related to a central reaction in an area of self-nominated interest. Requires replication of the reaction in the laboratory and explanation of utility in both general and chemical terms. Focus is on linkage between experimental work and use/manipulation of chemical symbols and equations.	Molecular structure, ions, bonding, writing and balancing equations, mole concept, theoretical and empirical yield	Laboratory and research journal 10 minute presentation	High
	1b	SA	Theory Exam 90 minutes	Standard written examination: Mixture of multiple choice, short answer and extended response questions.	Atomic structure, electron configuration, ions, bonding, periodic trends, writing and balancing equations, mole concept	Written answers to examination questions	Low
	2a	ERT	Research Task 9 x 70 minute lessons	Students select a contemporary chemical topic (e.g. use of acid leaching in engineering/mining, drug identification in rainforest plants/fungi, identification of food trees in koala ecology, teeth whitening procedures in dentistry, nutritional content of junk foods) and conduct independent research into the underlying chemistry of the system, seeking information relating to practices designed to manipulate reaction rate and yield through manipulation of temperature, concentration, enzymes and catalysts.	Reaction rate, effect of temperature, concentration, enzymes and catalysts on reaction rate, rate laws	Research journal 1000 word written report	High
	2b	SA	Theory Exam 90 minutes	Standard written examination: Mixture of multiple choice, short answer and extended response questions	Endothermic and exothermic reactions, reaction rate, factors that affect reaction rate	Written answers to examination questions	Low
	3	SA	Theory Exam 90 minutes	Standard written examination: Mixture of multiple choice, short answer and extended response questions	Solubility, precipitation and acid-base chemistry	Written answers to examination questions	Low

	4a	EEI	Experimentation and Research Task 18 x 70 minute lessons	Students are presented with a forensic science sample kit and supporting story and asked to apply knowledge to design and conduct experiments that will determine chemical identity contents of 2 x liquid, 1 x metal and 4 x soil samples.	Analytical chemistry, quantitative chemical analysis (solubility, chemical identity)	Laboratory and research journal 2000 word written report	Medium
	4b	SA	Theory Exam 90 minutes	Standard written examination: Mixture of multiple choice, short answer and extended response questions	Quantitative analytical chemistry, acid-base chemistry	Written answers to examination questions	Low
12	5a	EEI	Experimentation and Research Task 18-24 x 70 minute lessons	Students adopt the role of resident chemist in establishing a self-sustaining research facility in a pristine landscape (each student assigned a unique bioregion). Task requires design and conduct of experiments that will allow them to identify, develop and refine sustainable methods of providing food, drinking water, fuel, refrigeration and electricity for the facility.	Organic chemistry, calorimetry, electrochemistry	Laboratory and research journal 10 minute presentation 2500 word written report	Medium
	5b	SA	Theory Exam 90 minutes	Standard written examination: Mixture of multiple choice, short answer and extended response questions		Written answers to examination questions	Low
	6a	ERT	Research Task 12 x 70 minute lessons	Students select an equilibrium system of commercial, social, biological, ecological or historical significance and conduct independent research into how kinetics of the system have been and can be manipulated to develop, maintain and improve chemical outcomes for the benefit of individuals, communities or industries.	Chemical equilibrium, equilibrium constants, reaction quotient, Le Chatelier's principle	Research journal 2500 word written report	High
	6b	SA	Theory Exam 90 minutes	Standard written examination: Mixture of multiple choice, short answer and extended response questions		Written answers to examination questions	Low
	7	SA	Practical Exam 3 x 70 minute lessons	Students are randomly allocated a specific clock reaction (maximum three students per reaction) and asked to develop and refine a strategy for achieving a permanent colour change on, or close to, a designated target time (unique for each	Oxidation numbers, reduction-oxidation reactions and systems	Laboratory and research journal 10 minute practical demonstration	Medium

				student). Students have the option of working individually, or with other students, during the experimentation and demonstration stages, but are required to submit individual laboratory/research notes.			
	8a	ERT	Experimentation and Research Task 10 x 70 minute lessons	Students select two from a folio of ten problems/questions and conduct independent research and experimentation to generate solutions/answers. Journal from Task 8a is taken into Task 8b examination.	Quantitative analytical chemistry, organic chemistry, polymer chemistry, reduction-oxidation reactions and systems, acid-base and buffer systems	Laboratory and research journal	Medium
	8b	SA	Theory Exam 90 minutes	Tailored written exam, with questions based on topics investigated during Task 8a.		Written answers to examination questions	Medium

Table 3: Correlation between Achievement on Personalized and Non-Personalized Assessment Tasks

All linear (Pearson's r) correlations between variables were significant at the p < 0.001 level for all pairwise comparisons.

	Pers. KCU	*Pers. IP*	*Pers. EC*	*Pers. Overall*	*Non-Pers. KCU*	*Non-Pers. IP*	*Non-Pers. EC*	*Non-Pers. Overall*
Pers. KCU	–							
Pers. IP	0.937	-						
Pers. EC	0.948	0.972	-					
Pers. Overall	0.962	0.989	0.991	-				
Non-Pers. KCU	0.933	0.805	0.817	0.824	-			
Non-Pers. IP	0.879	0.790	0.826	0.817	0.864	-		
Non-Pers. EC	0.936	0.847	0.852	0.861	0.955	0.887	-	
Non-Pers. Overall	0.948	0.844	0.862	0.865	0.974	0.945	0.981	-

Differences between Personalized and Non-Personalized Tasks: To determine whether variation in performance on personalized and non-personalized tasks was due to differences in general academic capacity required control for high levels of inter-correlation (Table 3).

An index of differential performance was generated through linear regression (dependent variable: Personalized Overall, independent variable: Non-Personalized Overall). The regression model (Fig. 4) was highly significant ($R = 0.865$; $R^2 = 0.748$, $F = 222.496$; $p < 0.001$) and standardized residual scores were retained for use in regression (generalized linear model) against the Academic Performance Index.

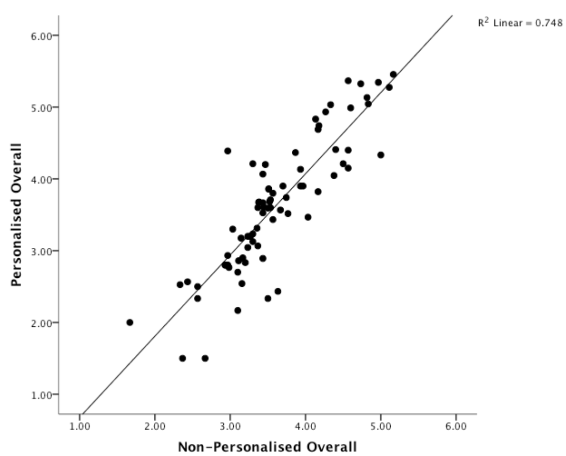


Figure 4: Linear Relationship between Performance on Personalized and Non-Personalized Assessment Tasks

Table 4: Linear Relationships between Performance on Personalized and Non-Personalized Assessment Tasks

Independent Variable	*Dependent Variable*	*R*	R^2	*df*	*F*	*p*
Non-Personalized KCU	Personalized KCU	0.933	*0.871*	*1, 76*	*514.505*	*<0.001*
Non-personalized IP	Personalized IP	0.790	0.624	1, 75	124.408	<0.001
Non-personalized EC	Personalized EC	0.852	0.726	1, 75	199.007	<0.001
Non-personalized Overall	Personalized Overall	0.865	0.748	1, 75	222.496	<0.001

Similar regression-based transformations were performed for the personalized and non-personalized KCU, IP and EC grades (Table 4).

To determine whether KCU, IP and EC performance varied for personalized and non-personalized tasks, a series of comparative analyses were undertaken. The nature of the dataset meant that viability of parametric methods could not be confirmed through tests for homogeneity of variance and relatively low-power non-parametric tests were adopted as a conservative alternative.

To determine whether grades for personalized and non-personalized tasks were consistently similar or different, Kendall's co-efficient of agreement (W) was calculated for the Overall, KCU, IP and EC datasets.

Post-hoc pairwise comparisons between personalized and non-personalized KCU, IP and EC grades were then performed using Wilcoxon's signed ranks test, with a Bonferroni correction to significance levels (α = 0.05/number of tests).

RESULTS

The academic performance index accounted for up to 57% of the variation in performance on personalized tasks (Fig. 5a) and 82% of variation in performance on non-personalized (Fig. 5b) tasks (Table 6). There was no significant linear relationship (Fig. 5c) between API and differences in performance on personalized and non-personalized tasks (Table 6).

Table 5: Linear Relationships between Academic Performance Index and Performance on Chemistry Assessment Tasks

Independent Variable	*Dependent Variable*	*R*	R^2	*df*	*F*	*p*
Academic Performance Index	Personalized Overall	0.752	*0.566*	*1, 71*	*92.523*	*<0.001*
	Non-personalized Overall	0.817	0.663	1, 70	140.40 2	<0.001
	Personalized x Non-Personalized Residual	0.086	0.007	1, 70	0.516	0.475

a)

b)

c)

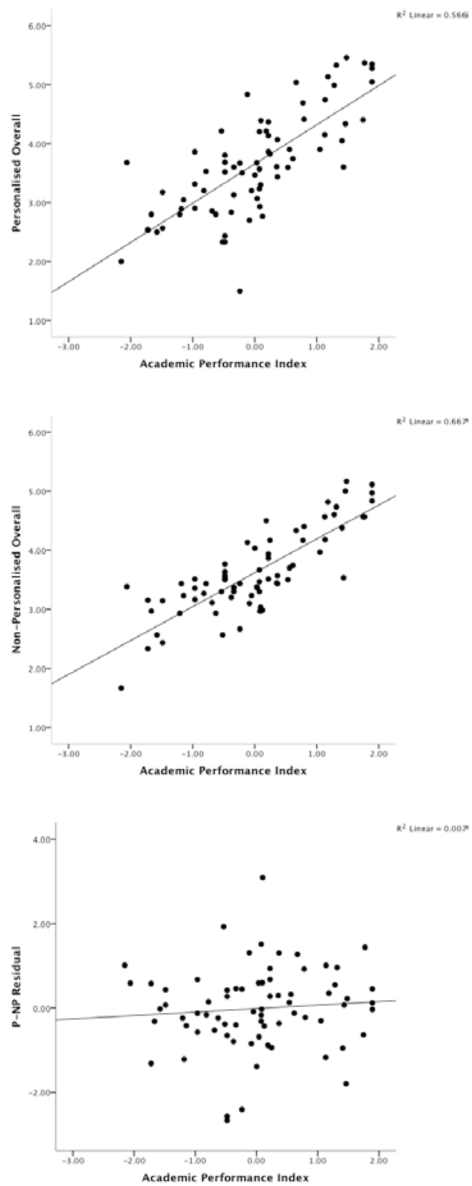


Figure 5: Achievement on Chemistry Assessment Tasks as a Function of Academic Performance Index

The academic performance index showed a significant ($p < 0.001$) linear relationship with performance on both personalized (a) and non-personalized (b) tasks. Differences in performance on personalized and non-personalized tasks (c) were not significantly related to the academic performance index.

Table 6: Linear Relationships between Academic Performance Index and Differences in Performance on Personalized and Non-Personalized Assessment Tasks

Dependent Variable	*R*	R^2	*df*	*F*	p_1
KCU Residual	0.102	*0.010*	*1,70*	*0.730*	*0.396*
IP Residual	0.197	0.039	1,70	2.815	0.098
EC Residual	0.101	0.010	1,70	0.726	0.397

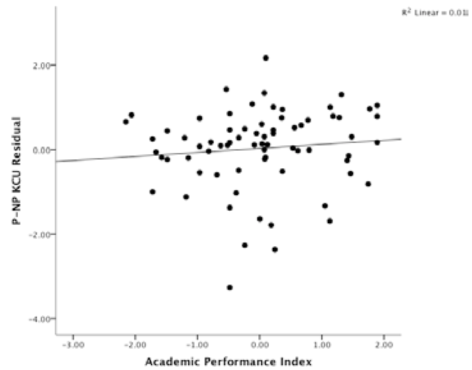
When KCU, IP and EC residuals were analysed separately, the Academic Performance Index explained no more than 10% of variation in KCU and EC (Table 6). The percentage of variance explained rose to 20% for the IP residual (Table 6), but none of the regression models were significant (Fig. 6).

The Friedman test ($\chi^2 = 60.290$, $df = 5$; $p < 0.001$; n = 77) indicated that there were significant differences between personalized and non-personalized achievement (Fig. 7). Pairwise Wilcoxon-rank tests indicate that the difference was due to a tendency for individuals to score higher for KCU on non-personalized tasks, and higher for IP on personalized tasks (Table 7). No significant differences in performance were detected for medium or high-level personalization (Table 7).

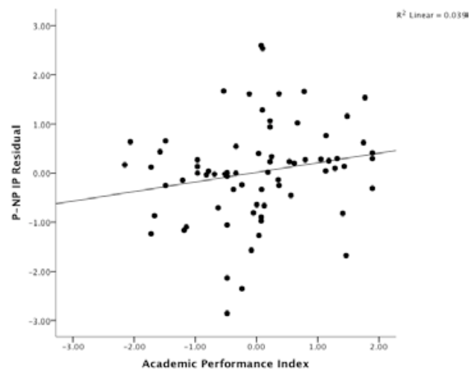
Table 7: Wilcoxon-Rank Tests for Differences in Performance on Personalized and Non-Personalized Tasks

Dimension	*N*	*Z*	*p*	*Directionality*
KCU	78	-2.390	0.017	Non-personalized > Personalized
Med. vs. High		-1.143	0.253	No difference
IP	77	-3.503	<0.001	Non-personalized < Personalized
Med. vs. High		-0.034	0.973	No difference
EC	77	-0.107	0.915	No difference
Med. vs. High		-2.030	0.042	No difference

a)



b)



c)

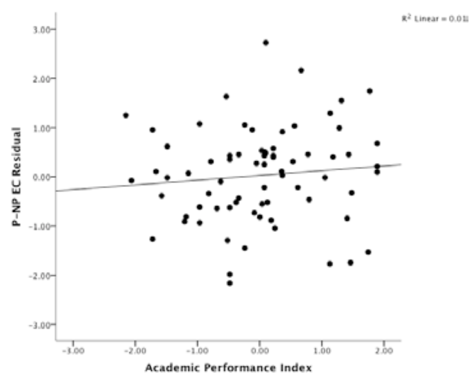


Figure 6: Differences in Achievement on Personalized and Non-Personalized Tasks as a Function of Academic Performance Index

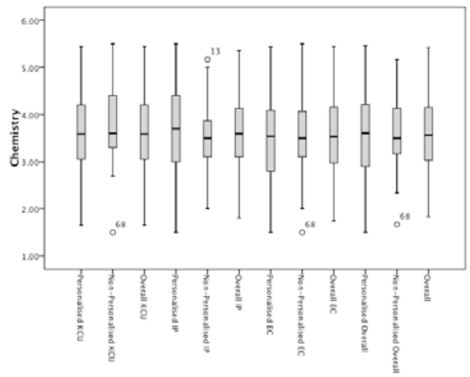


Figure 7: KCU, IP and EC Achievement on Personalized and Non-Personalized Assessment Tasks

DISCUSSION

Concern that numbers of academically competent students progressing to tertiary study of science are insufficient to meet the needs of new knowledge-based industries is catalysing global reform of science education. Arguments for change often evoke a rhetoric of teacher deficiency, epitomized by statements about teachers that are “boring or lacking in subject knowledge” and the need to teach science “earlier and better” (p. 1; Universities Australia, 2012). As well as perpetuating a dysfunctional mythology that the ability to do, and therefore teach, science is a unique trait possessed by a relatively small number of elite individuals, such statements have limited utility within the classroom. This study demonstrates that there is a strong correlation between general academic ability and performance in senior chemistry, but as predicted by teaching and learning theory, a holistic, personalized approach to teaching and assessment has quantifiable potential to enrich the learning experiences of individuals and develop crucial awareness of the philosophies and practices of science.

That general academic ability is a powerful predictor of grades is entirely consistent with expectations. Basic aptitude for learning is heritable (Vinkhuyzen, vanderSluis, Posthuma, & Boomsma, 2009) and individuals who do well in Mathematics would therefore be expected to perform well in subjects such as English and Science. It is also widely known that increases in core language, literacy and numeracy skills correlate with increased performance across all academic fields (Council for the Australian Federation, 2007; Hilton, 2006; Rubin, 2008; Sara, David, & Anthony, 2007; State of Queensland, 2002; Volante & Ben Jaafar, 2008).

The latter point has been used to justify standardization or nationalization of assessment in many countries, but critiques of national testing regimes suggest that one of their more insidious effects is establishment of merit-demerit cultures that reinforce disengagement of students who most need support, and encourage teachers to abandon creative, reflexive practices that foster higher-order thinking in favour of narrow, prescriptive methods designed solely to elevate test scores (Anagnostopoulos, 2006; Batagiannis, 2007; Creese, 2005; Hartley, 2008; Kyriakides, 2004; Leighton et al., 2010; Manzo, 2003; Schulte, Schulte, Slate, & Brooks, 2002).

Although criticism that national testing undermines the abilities of education professionals to diagnose the unique and situated instructional requirements of individual students has focused primarily on language, literacy and numeracy testing in lower grade levels (Kyriakides, 2004; Nagy, 2000), it is relevant in this context. Moon et al. (2003) have shown that classroom environments focused on external testing generate boredom and resentment in high ability primary students and emphasizing external measures of competitive attainment frustrates both performance and engagement even in high-achieving tertiary cohorts (Stallman, 2012).

The significance of this in the secondary science classroom lies in the fact that, by the time students reach the post-compulsory level, psychosocial factors become at least as, if not more, important than innate ability. In a study of students from over fifty countries, Montt (2011) found that opportunity to learn is crucial for student achievement, but links this to generic notions of teacher quality rather than any concrete recommendations for teaching practice.

Studies that do attempt to articulate a basis for quality teaching in science education often emphasise the importance of inquiry methods. Publications of this nature include countless theoretical expositions and applied examples of the inquiry method; the majority of which suggest, imply or demonstrate that inquiry is effective, while a handful focus on issues and problems with implementation in various settings. What this study adds to the body of literature is quantitative evidence that inquiry works because it goes beyond development of domain-specific knowledge and cultivates intrinsic motivation to learn.

The first indication of a difference in performance on personalized versus non-personalized tasks comes from the fact that general academic ability explains up to 87% of variance in performance on written exams, but only 53% of variance on ERTs and EEIs. To understand the full significance of this finding, it is necessary to consider the suite of skills and abilities that are tested in each type of task.

The structure of the QSA syllabus, and learning programs that are consistent with it, is such that the overall grade is derived from a combination of KCU, IP and EC. The KCU and EC strands map to classic conceptualisations of attributes that students should develop through exposure to secondary chemistry. In the case of KCU, this includes tasks such as reading and manipulating chemical formulae and equations, and the quantitative information that pertains to, or arises from, them. In students of high ability, understanding of algorithms and procedures should be developed to such an extent that they can rearrange and reconfigure problem-solving schemata to fit unfamiliar scenarios. The EC strand focuses on articulating and conveying the meaning of chemical information and data in different contexts. These two strands have analogues in almost all areas of human endeavour, but IP is unique to science in that it focuses on philosophical frameworks based on generation and testing of hypotheses linked to the physical manipulation of scientific systems or models.

Written exams do not provide extensive opportunity for students to demonstrate IP skills because they are, by definition, generic question sets that are answered by all individuals in a given cohort or class: Responding with information that is peripheral or irrelevant detracts from, rather than adds to, the quality of the response. Written exams are important tools for allowing students to demonstrate KCU and EC, but IP is more effectively and appropriately assessed by other means. A disproportionate IP loading is therefore a diagnostic feature of any task other than a written exam because it requires the individual to explore what lies behind and beyond the model. ERTs and EEIs do however, retain high loadings for KCU and EC. Task 1a, for example, is conceptually no different to a written exam in that the basic questions (mole/molarity and yield calculations) are identical for each student. What differs in this case is not the core content, (opportunity to demonstrate KCU), but the context (the system under investigation).

Despite differences in the number of assessment items included for each cohort, the fact that methods of generating indices of student performance did not capture information about exact traits and abilities associated with particular subjects (e.g. music versus mathematics) and a general trend for student performance to decline on transition to the senior years, the unique nature of the IP construct is supported by the results: KCU, IP and EC show differing degrees of dependence on general academic ability and, while KCU tends to be higher for written exams, IP reaches its maximum for all students when they are engaged in experimentation and research.

There is a degree of circularity in this. Performance against IP criteria is higher when tasks are personalized because any given example of a genuine inquiry task must be, to at least some extent, self-directed, but what this really means in terms of the impact of personalized research and experimentation (inquiry) tasks is that what is reflected in the IP grade is a combination of investigative ability *per se*, and the extent to which the individual engages with the process of investigation.

If we are serious about developing and maintaining a capacity for creativity within the field, science educators must not underestimate the significance of this point.

A survey of 1 100 tertiary science students from the Netherlands shows that motivational factors do vary by discipline, with Law and Humanities students driven by generic conceptualisations of excellence, while physics students were motivated by the idea of learning itself (Scager et al., 2012). A commissioned study of Australian tertiary students enrolled in Science, Technology, Engineering and Mathematics subjects however, indicates that career and/or lifestyle aspirations have greater significance for science students than students of the humanities (Universities Australia, 2012). The Australian study also claims that science students are more likely to be identified as one of sixteen unique personality types (ISTJ - Introverted, Sensory, Thinking and Judgmental) on the Myer-Briggs personality scale.

There are two issues associated with this statement. The first is relatively minor in that the authors ignore the fact that this is one of three (from 16 in total) personality types that are also overrepresented in the general population. The second point however, is problematic because it reinforces perceptions that those who wish to succeed in science must be in possession of a set of pre-existing traits, characteristics and skills before they enter the science classroom. This is simply not consistent with what is known about how and why we learn.

The superhuman intellect of the uniquely creative ‘mad scientist’ is a myth: A study of 291 eminent individuals recognized as creative in their field of endeavour actually demonstrated that scientists are the least likely to display traits associated with, or predictive of, mental illness (Glazer, 2009) and creative output hinges upon essentially random, unpredictable interactions between personal, social and environmental characteristics (Simonton, 2003b). The likelihood of creative output however, can be increased by providing individuals with opportunities to develop high levels of domain-specific knowledge, become competent at applying it and find relevance in areas of personal interest (Schmidt, 2010, 2011a).

Decreasing the variability in quality and quantity of learning experiences is an important step toward construction of a society where achievement in various fields of endeavour arises through talent, ambition and effort rather than the perpetuation of discriminatory policies and practices (Dewey, 1916; Montt, 2011). Widening participation in tertiary education is also an important mechanism of change because it is linked to emotional, mental and economic health (Cheung & Chan, 2009), but tertiary institutions represent one part of a far broader educational system.

Regardless of the field of endeavour, the current pace of social and technological change means what is taught or learned in education and training will be irrelevant to workplace practice within five years (Kilpatrick & Allen, 2001). Any reform of educational policy and practice will therefore be ineffective in the longer-term unless it is enacted in a manner which acknowledges that prescriptive approaches will only ever meet the needs of a relatively small number of individuals, for a limited period of time (Belanger, 1999). Rowlands (2011) places this in context by pointing out that the reality of scientific practice in the 21st century is multidisciplinary. In this environment, skills and knowledge are, and must be, acquired as required and meaningful creativity depends on intrinsic engagement.

Engagement with learning in any field is invariably personal. Triggering and sustaining student interest requires recognition that interest itself is unique because it consists of both cognitive and affective elements (Hidi, 2006). Kauffman et al. (2008) have previously cautioned against a tendency to misinterpret activities such as one-to-one instruction as genuine personalization and their point is supported by empirical evidence. A study of 123 undergraduates showed that neither learning style nor personality traits predict engagement with specific (ICT-supported) learning tasks (Nilsson et al., 2012), but students are less distracted and more engaged with learning when given materials that connect to areas of personal interest (Danzi, Reul, & Smith, 2008).

Surveys of science teachers in middle and high school environments reveal deep awareness that calls for personalization and inquiry give rise to conflicting messages about good practice. Administration and government bodies emphasise a need to develop general academic skills, but tertiary science institutions and science education academics insist that rich, open-ended inquiry tasks are the only effective way to deliver quality science education (Aydeniz & Southerland, 2012).

Tensions between sectors are not unique to science education. All reform takes place in contested sociocultural space and delivers both positive engagement of teachers, and improved student outcomes, only when it is planned, designed and implemented through systems based on trust and mutual influence (Afdal, 2012). Recognition that quality education systems must allow flexibility in delivery of content is a hallmark of high-achievement: The high-performing Finnish system for example, is currently undergoing reform to restore teacher autonomy and increase recognition that progression to tertiary study is not, and should not be, the sole aim of the secondary system (Pyhalto, Soini, & Pietarinen, 2011).

This is a significant point. Despite widening participation in post-compulsory education, youth unemployment remains high even in OECD countries (Quintini & Martin, 2006) and over education creates as many problems as under education for individuals, communities and nations (Barone & Ortiz; Linsley, 2005; Messinis, 2007; Quinn & Rubb, 2011; Romanov, Tur-Sinae, & Eizman, 2008). This is particularly true in the sciences, where over graduation of PhD students has previously created employment and training crises (Kendall, 2002; Gemme & Gingras, 2012; McCulloch & Thomas, 2012)).

Declining enrolments in science subjects at secondary and tertiary level are potentially problematic, but tertiary science educators and practicing scientists are calling for reform of the secondary sector without any significant appreciation of the policies and practices that govern this domain. Numerous tertiary science educators for example, are operating in an environment of increased accountability for their own teaching and learning practices. As they encounter issues and problems associated with definitions and perceptions of inquiry, they assume that their own experiences are paralleled in the secondary sector. Buck et al. (2008) for example, point out that the call to inquiry in undergraduate education is ubiquitous, but claim that there has been little to no clarification of what inquiry means in terms of teaching and learning practice and Herron (2009) points out that this is particularly problematic in an environment where teaching staff are drawn from the ranks of graduate students, few of whom have any awareness of, or appreciation for, teaching and learning theory.

In a secondary context, the problem is not that there has been no clear articulation of what constitutes an inquiry-based learning program, but that its manifestation can and should vary. Implementing inquiry requires educators who are able to diagnose, and respond to, the prior knowledge and metacognitive abilities of specific cohorts and individuals. This is one reason why teachers with similar sociocultural backgrounds to their students are often crucial (Kelly-Jackson & Jackson, 2011). It is important to note however, that this contradicts, rather than supports perceptions that those who would make good teachers can be identified prior to engagement with the profession.

Efficacy of education in a secondary context is heavily dependent on systems of shared belief. When teachers and students believe that they are working toward common goals, within a just and fair framework of attainment, the end result is an authenticity of self and society (Resh, 2009) that is reflected in, but not limited to, variations in power dynamics between students and teachers across different educational environments. In France for example, students expect, and therefore respond to, teachers who are distant and authoritative, but in the Netherlands, a more relaxed, informal approach delivers stronger interpersonal connection/validation (Hornikx, 2011).

The key point here is that attempts to articulate, ascertain or predict teacher quality are often counterproductive. A study of 368 education students show that specific personality types may be attracted to specific areas such as special education, or mathematics teaching (Rushton, Mariano, & Wallace, 2012) and there is no doubt that certain characteristics, such as suspension of judgment and flexibility, are essential when dealing with adolescents, but the exact mix of personal and academic characteristics required for success depends on complex, dynamic interactions that are underappreciated by those outside of the profession. Shortages of teachers with formal qualifications in pure science are a product of these interactions. Gaps between pedagogical and content knowledge may be filled through targeted programs such as content-specific Masters qualifications (Huntoon & Baltensperger, 2012), but content knowledge will not compensate for a disposition that is incompatible with teaching in general, or specific, contexts (Gawlik, Kearney, Addonizio, & LaPlante-Sosnowsky, 2010).

Highly variable, context-specific affective and interpersonal factors are, by nature, difficult to control and measure. A study of 579 British undergraduates for example, found no significant link between intelligence and learning style and only 25% of variance in learning was explained by the interplay between intelligence and personality (vonStumm & Furnham, 2012).

The decision to omit measurement of affective and social factors from this study was justified because any difference in performance on personalized and non-personalized tasks would be statistically significant only if it were able to transcend inter and intra personal factors. That tailoring assessment tasks to individual interests generates significant differences in engagement and/or investigative skills indicates that reform of science education should take care not to constrain flexibility.

The reality of teaching and learning practice is that reforms emphasising external, nationalized tests of ability and aptitude reduce, rather than enhance, differentiated practice (Anderson, 2012; Moon et al., 2003). Tailoring tasks to meet the needs of different individuals and cohorts also requires adequate time for preparation, planning and reflection. This is acknowledged in some systems, where teachers are given a maximum of three classes (Gao, 2011), but it is also important to note that this is often due to expectations that primary and secondary teachers should be active in educational research and publication. This is not always realistic because it underestimates the value of time spent preparing individual learning plans for multiple classes, each of which may contain between twenty and thirty students. The tertiary sector is recognizing that there are reasons to separate the functions of teaching and research (M. Barrow & Grant, 2011; Bexley, Arkoudis, & James, 2012; Blackmore, 2009; Myer & Evans, 2005; Nair, Bennett, & Mertova, 2010; Ramoniene & Lanskoronskis, 2011), and the primary and secondary sectors must also acknowledge that imposition of research loads will constrain teaching.

What this study highlights is a need for greater awareness and interaction across different sectors of science education. To evoke a culture of competitive attainment based on identification of individuals who possess innately superior ability in science, or science teaching, will do little to ensure quality outcomes. Science education is in danger of running aground in entrepreneurial and sociocultural terrain, when it is the developmental and psychometric discourses that hold the key to developing and implementing learning programs that activate and utilize students' intrinsic motivation to learn. Not only is this the only truly potent and effective stimulus for quality educational outcomes (McMeniman, 1989; Jacobs & Newstead, 2000; Nunan, 2000), it is the only pathway to genuine creativity (Schmidt, 2010, 2011a; Simonton, 2003b).

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