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The development and validation of an instrument – the Technological Profile Inventory – to determine students' levels of technological literacy in South Africa

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Abstract

In this article we describe the development and validation of an instrument – the *Technological Profile Inventory* (TPI). The instrument can be used to determine students' level of technological literacy. The items used in the TPI were drawn from a previous study [6] and were based on a rigorous qualitative analysis of interview data which was in turn informed by categories that emerged from a phenomenographic analysis. Data were collected from four groups of students, three groups of first year students at university, Engineering (n=167), Commerce (n=65), Arts (n=218), and one group of high school students (n=179). The students' responses to the TPI were subjected to exploratory factor analysis and Cronbach alpha testing, as well as a one-way multivariate analysis of variance (MANOVA). The result of the analysis was a modified version of the TPI where the data were found to be reliable and valid. The significant factors that defined the 'nature of technology' were found to be the view of technology as either an *Artefact* or related to a *Process*, while those constituting 'interaction with technological artefacts' were *Direction/Instruction* and *Tinkering*. A cohort analysis suggests Engineering students are statistically more likely to view technology as a process and interact with technological artefacts with less fear and more self-initiation (*Tinkering*) – a more advanced technologically literate position. On the other hand the Arts students are more likely to expect direction or instruction from an authority figure (*Direction/Instruction*) when interacting with a technological artefact - a less technologically literate position. Further work involves determining how to meaningfully combine the scores achieved by an individual completing the TPI to ultimately determine a score indicative of their applicable level of technological literacy.

Keywords: Technology, technology literacy, phenomenography, engineering education.

1 INTRODUCTION

In 1994 South Africa saw a significant shift toward a non-racial and democratic society. This shift required social changes to ensure that the country could cater for its people irrespective of race. Education was a vehicle to provide access to all races, and a curriculum re-structure was a necessary first step. Given that a country in transformation requires a workforce highly knowledgeable of current technologies to develop a viable economy, technology, in general, is an engine house of the development and prosperity of any nation in terms of its historical, cultural, social and economic perspectives [1]. As a consequence, technology education was introduced for the first time to the majority of South African school students through the subject Technology.

The intention of the Technology curriculum was to create technologically literate school students with a basic level of technological literacy by Grade 9 [2]. However, given the current South African curriculum, many students formally develop their levels of technological literateness up to Grade 9, and then encounter technologically-focussed programmes only at tertiary level, creating a three-year gap between high school and tertiary level technology-based studies. One of the consequences of this lag could be that students who enter first year university programmes, for instance Engineering, struggle to succeed to the next level of study [3]. It might be argued that students entering an Engineering programme should have more than a basic level of technological literacy in order to have the best chance of success.

In order to explore students' levels of technological literacy, it is necessary to accurately determine just what these are at the individual level. This article introduces an instrument to determine a students' level of technological literacy – the *Technological Profile Inventory* (TPI). The study would make an important contribution toward the development of an instrument for determining students' levels of technological literacy – ranging from high school to university levels – which could inform high school curriculum development, and the first year university selection process for the best chance of student success in technologically-focussed programmes at university.

2 WHAT DOES IT MEAN TO BE TECHNOLOGICALLY LITERATE

There have been many definitions of what it means to be technological literate. Ingerman and Collier-Reed [4] suggest that it is difficult to describe technological literateness because "there is no one universal set of requirements" that satisfies it (p.138). A further confounding factor is what they describe as "socio-cultural context" [Ibid]. Furthermore they suggest that typical definitions focus nominally on the content of technological literacy with little recognition of the importance of function - a complementary feature of technological literacy. They further argue that the function of technological literacy is the "mode of action by which technological literacy fulfils its purpose" drawing on the definition of function in the Oxford English Dictionary [5 as cited in [4], p. 139]. Thus, action (or doing) forms a central part of all aspects relating to being technologically literate, and therefore a feasible definition for a person to be considered technologically literate, entails that they "understand the nature of technology, have a hands-on capability and capacity to interact with technological artefacts, and … be able to think critically about issues relating to technology" [6, p. 15].

People have different levels of technological literacy ranging from basic to more advanced. A common view is that technology equates with computers [7]. Surveys, like the two Gallup polls, support this view ([8], [9]). In the two Gallup studies, undertaken to determine what North Americans think about technology more than two-thirds of respondents indicated that their top of mind response when they heard the word technology was computers. This level, one might argue, is basic. Within this level "people can, and do, live without the faintest notion of the nature of technology" [10]. Importantly, this basic level might prevent the innate qualities associated with technological literacy to be "put into action" [6]. On the other hand, those who understand the nature of technology, and "put into action" the innate qualities they have [4], are arguably likely to be more technologically literate.

In South Africa, the emphasis of technology education is unfortunately often focussed on learning how a computer is used as a tool more than learning "about" computers [11]. The concern in technology education should rather be the technological process – that is, how the learner understands concepts, relationships, problem-solving, analysis and evaluation – not proficiency in a skill [12]. The technological process can be described as "a cycle of investigating problems, needs and wants, and the designing, developing and evaluating of solutions in the form of products and systems" [13, p. 86]. Through educating in this way, the student should understand that technology is more than the finished product, or technological artefact. The process of making (planning and designing), understanding how the technological product can be used beneficially, ethically and responsibly, as well as about understanding systems is likely to guide learners to become technologically literate. This implies that students who understand the technological process, are likely to develop their level of technological literacy, so that they can enhance the skills in line with Collier-Reed's [6, p.15] definition thereof.

For instance, given that Engineering degrees by design lead to technologically focussed vocations, one could reasonably assume that seeing technology simply as computers is not useful. Although one could assume that a graduate attribute of an Engineering programme should be technological literacy, we would argue that it would improve the chance of success of students in a programme if they entered the programme with a more developed conception of the nature of technology and level of technological literacy.

Therefore, in the present study, a new instrument is developed to determine students' levels of technological literacy through validation and reliability testing. The instrument will further be tested to determine whether it could possibly differentiate between various vocational groups.

2.1 The Technological Profile Inventory

In previous work Collier-Reed [6] interrogated the dimensions of technological literacy and after a phenomenographic analysis of interview data described five qualitatively different ways of experiencing the 'nature of technology' and four qualitatively different ways of experiencing 'interacting with technological artefacts'. The work is further described and developed ([3], [4], & [14]). These categories of description are presented in Table 1.

Table 1. Ways of experiencing the nature of technology and interaction with technological artefacts

The nature of technology is	Interaction with technological artefacts
An artefact	Direction
The application of artefacts	Instruction
The process of artefact progression	Tinkering
Using knowledge and skill to develop artefacts	Engaging
The solution to a problem	

We argue that collectively, these dimensions of technological literacy satisfy the core content requirements for what it means to be technologically literate ([3], [6], & [14]). In order to be able to classify students relative to these categories, and hence ultimately to be able to describe their technological profile, a series of statements were developed, that could be used to interrogate students' views on the dimensions of technological literacy. It was important the statements were in fact representative of – or attributable to – the categories under consideration (see, for example, [3]).

In order to ensure this congruence, the interviews that were previously phenomenographically analysed were reanalysed with the focus now on the individual. Consequently, a 41-item pilot instrument emerged from this analysis. The instrument was subjected to wide-scale testing to confirm the validity and reliability of the items, resulting in a 23-item questionnaire, which was expanded to a 30-item questionnaire with the aim of strengthening some of the factors [3]. The 30-item revised TPI questionnaire is the subject of the present study.

3 METHODOLOGY

Data were collected from a combination of 629 high school and university students. The total sample was divided between high school students (179 students – Grades 9 to 12) and students in their first year of study at the University of Cape Town (UCT) - split between Engineering (n=167), Commerce (n=65) and the Arts (n=218). The high school students were drawn from a group who participated in a Science Exposition, an annual competition where science- and technology-based projects are displayed. On the whole, these students are considered to be innovative and academically strong in subjects like science. Similarly, UCT is considered to be the best university in Africa and thus students who enter this university are considered to be good academic candidates.

Participants were required to supply biographical information in the form of their age, gender, degree programme and grade at school. From this information, it was determined that the sample consisted of 47.1% males and 50.9% females – thirteen did not indicate their gender. The average age of the students was 18.7 years (*SD* = 3.18), with 20 students who did not indicate their age.

The participants were informed that the purpose of the study was to explore their ideas and experiences about technology. The questionnaires were administered personally to the university students to ensure consistency in the instructions given to the students and to answer possible queries. During the instruction session, the students were told that completion of the questionnaire was voluntary and that all responses were confidential. The school students, on the other hand, required signed parental consent before completing the questionnaire. Thus, they took the questionnaire home to their parents who provided consent allowing the students to decide whether they were prepared to complete it. The parents were able to guide the students through the instructions if required. The response rate for this group of students was 69%, while for the university students were 98%.

Participants were required to mark on a seven-point Likert scale [15] their level of agreement with each item on a scale ranging from Strongly Disagree to Strongly Agree. The questionnaire took between 13 and 20 minutes to complete.

The data collected from the students were used to examine the validity and reliability of the revised TPI. As a first step, a factor analysis was performed to group or cluster variables [16]. In order to perform a factor analysis, an appropriate sample size is required [17]. The sample size for the present study was appropriate. Tabachnick and Fiddell [17] reviewed the issue of sample size for factor analysis and suggest that 'it is comforting to have at least 300 cases for factor analysis' (p. 613), where in the present study the sample consists of 629 students. In addition, other researchers suggest that the ratio of the items to subjects is of importance [18]. Indeed, Nunally [18] recommends a ten to one ratio, that is, 10 cases for each item to be factor analysed. Others suggest 5 cases for each item [17]. The data in the present study fit the requirements for both sample size and case to item ratio.

For the revised TPI, a further index of scale reliability and validity were generated – the Cronbach alpha coefficient. This co-efficient has a range of between 0-1, with a value of between 0.7-0.8 being accepted as a good indication of reliability [16]. However, Kline [19] notes that although the generally accepted value of 0.8 is appropriate for cognitive tests such as intelligence tests, for ability tests a cut- off of 0.7 is more suitable. He furthermore states that when dealing with psychological constructs, values below 0.7 can, realistically, be expected because of the diversity of constructs being measured
– as in the case of the present study.

In order to find differences between the Commerce, Engineering, Arts and School students as highlighted by the revised TPI, a one-way between-groups multivariate analysis of variance (MANOVA) was performed to investigate group differences. Five dependent variables were used, namely, *Artefact*, *Process*, *Direction/Instruction*, *Tinkering* and *Engaging*.

4 RESULTS

4.1 Exploratory analysis of TPI

A major objective of the present study was to validate the questionnaire to determine students' levels of technological literacy. The data were collected from 629 students and used to examine the reliability and validity of the TPI. As a first step, the data were used to perform a principal component factor analysis followed by a varimax rotation (Table 2). Factor loadings of less than 0.30 have been omitted in Table 2.

Based on this analysis, items 14 and 22, (from the *Process* scale) and item 8 (from the *Tinkering* scale) were omitted from the factor analysis and from further analyses. The revised instrument consisted of 27 items. During the factor analysis, the *Direction* and *Instruction* scales merged, suggesting that students regarded *Direction* and *Instruction* in similar ways. This scale was subsequently re-named *Direction/Instruction*. The percentage of variance accounted for by the different scales varied from 3.82 to 17.82, with the total variance accounted for being 57%. Eigenvalues varied from 1.2 to 7.0 for the different scales (Table 2).

On the whole, the factors emerged in line with the categories presented in Table 1 – which was not unanticipated as the items themselves were developed based on a rigorous qualitative analysis of interview data which was in turn informed by categories that emerged from a phenomenographic analysis [6].

For the revised TPI instrument, a further index of scale reliability and validity were generated (Table 2). The Cronbach alpha reliability co-efficient was used an index of scale internal consistency. An analysis of variance (ANOVA) results were used as evidence of the ability of the scales to differentiate between the groups. Table 3 shows that the internal reliability – the Cronbach alpha coefficient – for the TPI scales ranged between 0.60 and 0.83.

Table 2. Factor Loadings for a Modified Version of the TPI in South Africa

Item No	Artefact	Process	Direction/ Instruction	Tinkering	Engaging
27	0.81				
25	0.75				
29	0.70				
3	0.58				
28		0.76			
23		0.75			
26		0.60			
10		0.66			
15		0.63			
09		0.62			
01		0.60			
19		0.48			
16			0.73		
17			0.71		
30			0.69		
12			0.69		
24			0.65		
11			0.60		
04			0.55		
20			0.53		
02				0.75	
07				0.66	
05				0.60	
06					0.71
18					0.67
21					0.64
13					0.62
% Variance	10.8	13.22	17.82	3.82	6.20
Eigenvalue	3.24	3.96	5.35	1.15	7.00

Factor loadings smaller than 0.30 have been omitted.

The sample consisted of 629 respondents.

Table 3. Internal Consistency Reliability (Cronbach Alpha Coefficient)

Scale	No. of Items	Alpha Reliability
Artefact	4	0.70
Process	9	0.72
Direction/ Instruction	8	0.83
Tinkering	3	0.64
Engaging	4	0.60

The sample consisted of 629 respondents.

This level of scale reliability is acceptable [19] and indicates that the scales are consistently measuring and capturing the students' level of technological literacy as they were experiencing it.

Taken together, the results from the factor analysis, as well as the index of scale reliability and validity (the Cronbach alpha reliability index) suggest that the TPI is reliable and valid and can therefore be used with confidence to determine students' level of technological literacy at both levels - first year university and high school.

4.2 Cohort analysis based on TPI data

A one-way between-groups multivariate analysis of variance (MANOVA) was performed to investigate group differences. Five dependent variables were used, namely, *Artefact*, *Process*, *Direction/ Instruction*, *Tinkering*, and *Engaging*.

Table 4 Differences in responses of the students in the four groups using a MANOVA

Dimension	Commerce			Engineering			Arts			School				
	M	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*F*	*p*
Artefact	2.9	1.1	65	2.8	1.3	167	2.7	1.15	218	2.5	1.2	179	2.3	0.078
Process	4.6	0.7	65	4.9	0.8	167	4.5	0.82	218	4.8	0.8	179	12.9	0.000*
Direction/ Instruction	3.1	0.9	65	2.9	1.0	167	3.3	1.13	218	3.2	1.1	179	5.9	0.001*
Tinkering	4.9	1.2	65	5.5	1.2	167	4.9	1.36	218	5.3	1.2	179	7.6	0.000*
Engaging	5.1	1.2	65	5.1	1.1	167	5.0	0.96	218	5.1	0.9	179	0.9	0.453

* $p<0.05$ The sample consisted of 629 respondents.

The results show that there was a statistically significant difference between the group responses (Commerce, Engineering, Arts and School students') to the TPI on the combined set of dependent variables *F* (15, 1715) = 6.32, *p* = 0.000. From this result it can be concluded that the groups have statistically significant differences in the levels of technological literacy.

When the results for the dependent variables were considered separately using a one-way analysis of variance (ANOVA), there was a statistically significant difference on the scales *Process F* (3, 625) = 7.86, *p* = 0.000; *Direction/Instruction F* (3, 625) = 7.06, p = 0.001 and *Tinkering F* (3, 625) = 11.93. Closer inspection of the mean scores indicated for each of the three scales, showed that for the scale *Process*, the Engineering students (*M* = 4.9, *SD* = 0.8) and School students (*M* = 4.8, *SD* = 0.8) showed higher levels of agreement with the statements than the Commerce students (*M* = 4.6, *SD* = 0.7) and Arts students (*M* = 4.5, *SD* = 0.8). For the scale *Direction/Instruction* the Arts students (*M* = 3.3, *SD* = 1.1) and School students (*M* = 3.2, *SD* = 1.1) showed higher levels of agreement with the statements than the Commerce students (*M* = 3.1, *SD* = 0.9) and Engineering students (*M* = 2.9, *SD* = 1.0). On the scale *Tinkering* the Engineering students (*M* = 5.5, *SD* = 1.2) showed higher levels of agreement, than the School students (*M* = 5.3, *SD* = 1.2), while the Commerce and Arts students showed similar levels of agreement (*M* = 4.9, *SD* = 1.2) and (*M* = 4.9, *SD* = 1.4) respectively.

5 DISCUSSION

The development and validation of a questionnaire – the *Technological Profile Inventory* (TPI) – to determine students' levels of technological literacy at school and first year university level is timely. The questionnaire provides teachers and students with an accessible means of determining and monitoring changes in technological literacy. It is rigorously designed and captures important aspects of the technological literacy.

This study involved the collection of data from 629 students at school and university. The data were analysed to determine the validity and reliability of the TPI, in terms of its factor structure, internal consistency reliability, and ability to differentiate between groups. The factor structure for the TPI indicated that students respond to *Direction* and *Instruction* in similar ways. Therefore, these two scales were combined to form one scale – and subsequently re-named *Direction/Instruction*. For all five scales (*Artefact*, *Process*, *Direction/Instruction*, *Tinkering*, and *Engaging*), items have a factor loading of at least 0.30 on their *a priori* scale and no other scale.

The internal consistency reliability estimate (Cronbach alpha coefficient) for each of the five scales was comparable with a previous study [3]. The results of one-way ANOVAs indicate that the TPI was able to differentiate between different groups. Overall, the validation provides for the confident future use of the TPI in high school and first year university students in South Africa.

A one-way MANOVA was used to investigate differences in scale scores between the Engineering, Commerce, Arts and School students. There was a significant difference for three of the five scales. For the scale *Process*, the Engineering students scored the highest implying that they tend to agree more with the advanced conception of the category the 'nature of technology' (Table 1). Interestingly the school students scored higher than both the Commerce and Arts students (Table 3), implying that these students very likely have a greater conception of the 'nature of technology' – which could be explained by the fact that these high school students were participating in a Science Exposition and as such were a self-selected group with arguably a particular 'technological' profile. These results suggests that the higher levels of agreement of all the groups of students in conceiving technology as a *Process* rather than an *Artefact* (Table 4) suggests that the university students entered their university programme with at least a basic level of technological literacy, and the high school students already have more than a basic level of technological literacy.

For the scale *Direction/Instruction,* contrary to the findings of Luckay & Collier-Reed [3] who found that the scale *Instruction* was less useful as a stand-alone scale (with a Cronbach alpha co-efficient of 0.62), it was found to be more meaningful combined as *Direction/Instruction* (with a Cronbach alpha reliability of 0.83 in Table 3). Combining the two scales (Table 2) suggests that students view them as similar ways of 'interacting with a technological artefact', where *Direction* is described by Collier-Reed *et al.* [14] as

> "the result of a directive by someone. It is not something that happens spontaneously as there is reluctance to making the first move toward approaching it. This category describes the experience as being on the outside looking in towards a technological artefact as a reified object, the artefact is placed on a 'pedestal' in an exalted, unapproachable position." (p. 298)

and *Instruction* is described by Collier-Reed *et al*. [14] as "receiving instruction via some means which enables the interaction with the artefact" (p. 299). Thus, being helped or guided through *Direction* or *Instruction* were ways of initiating some students to interact with a technological artefact. It is likely that these students lacked the spontaneity to interact with a technological artefact independently. Indeed, it was evident that in this sample, the Arts students required guidance to initiate their interaction with a technological artefact, surprisingly more so than the school students (Table 4) – again, not surprising given their profile.

For the scale *Tinkering*, described by Collier-Reed *et al.* [14] as

> "characterised by a self-initiating interaction with a technological artefact by beginning to tinker with it…[T]here is no need for instruction to enable the interaction. There is no sense of being intimidated by anything to do with the artefact…[They] recognise that an artefact has a variety of functions and set out to determine what they are and make the artefact operate." (p. 299-300)

The results in Table 4 show that the Engineering students display higher levels of agreement on the ítems for this scale, which implies that they are more likely to interact with the artefact through self- initiation, with little instruction (supporting the results on the scale *Direction/Instruction* in Table 4). This finding supports that of the authors [3] which suggests that the scale *Tinkering* plays an important role in describing the 'interaction with technological artefacts', and is important in distinguishing groups. Interestingly, the high school students were more likely to show less intimidation when interacting with technological artefacts than the Commerce and Arts students (Table 4). This result could imply that whatever level of academic development, some students have an innate ability to interact with a technological artefact, without being initiated by some form of direction or instruction from an outside source.

Thus, overall the one-way MANOVA results in Table 4 suggests that the TPI is able to differentiate groups, supporting anecdotal evidence that the Engineering students are more likely to have an advanced level of the 'nature of technology', and in the category 'interaction with technological artefacts' are more likely to self-initiate (*Tinkering*) when interaction with a technological artefact requiring less direction and instruction (*Direction/Instruction*) from other sources. However, the specific differences, and magnitude of the differences, calculated using effect sizes, between the groups should be calculated, but this is beyond the scope of the present paper.

The results from this study have implications for both professional development programs for teachers and classroom practices in South Africa as this instrument provides an important new tool for teachers, teacher educators, university lecturers and researchers. Teachers can adjust their learning environment towards a more focused promotion of a technologically literate environment.

6 CONCLUDING COMMENTS

The article had the objective of describing the development of an instrument – the *Technological Profile Inventory* (TPI) – to determine high school and university students' technological literacy. It was argued that the information from the instrument can be used to inform teaching practice, teaching programmes and learning environments.

The outcome of the analysis suggests that the instrument does collect useful data that can be used to differentiate between students who enter different faculties at university – but also groups of students who show the same potential based on their level of technological literacy.

The next stage in this project is to find the magnitude of the differences between the groups, and between which groups the magnitudes of the differences are the greatest. These could be determined through finding the statistical effect size. Furthermore, we need to determine how to meaningfully combine the scores achieved by an individual completing the instrument to ultimately determine a score indicative of their applicable level of technological literacy.

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