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The importance of supporting technological knowledge in post-primary education: a cohort study

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ABSTRACT

Background: Substantial research highlights the differences between scientific and technological knowledge. Considering that learning is heavily focused on the acquisition of knowledge, it is important to examine the individual and systematic implications of these types of knowledge.

Purpose: The purpose of this study was to examine the impact on overall educational performance as a result of engaging with technology subjects at post-primary level.

Sample: A five year cohort study was designed to gather longitudinal data from a total sample of 1761 pupils' grades from the Irish Leaving Certificate examination. The sample was distributed across four schools.

Design and methods: Grades from the Irish Leaving Certificate were selected because the examination is considered high stakes as it serves as the country's primary mechanism for matriculation into third-level education. Individual examinations are designed externally to schools by a government body ensuring the validity of each examination in capturing the holistic interpretation subject syllabi. Finally, a points system is used to score each examination facilitating comparisons between subjects.

Results: The results show that pupils who study the technology subjects are statistically significantly less likely to perform well overall in comparison to pupils who study science and mathematics subjects. They also show that for pupils who study the technology subjects, those subjects are statistically significantly likely to be their best performing subjects.

Conclusions: Due to the array of variables impacting subject selection, a definitive causal explanation cannot be deduced from the data for these results. However, it is possible to infer that the variance in knowledge types between the science and technology subjects has an impact on the results. A case is made that a compulsory technological component should be incorporated into educational curricula to provide a comprehensive and general education and to facilitate the holistic development of pupils.

KEYWORDS

Technological knowledge; scientific knowledge; national assessment; educational aims; learning

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Introduction

Learning is defined as 'a change in long-term memory' (Kirschner, Sweller, and Clark 2006, 75) and 'involves the acquisition of knowledge' (Mayer 2002, 226). This particular aim of knowledge acquisition is fundamental within education and arguably influences many other educational aims, such as social and emotional development, due to the increased breadth of knowledge and experience. Knowledge acquisition can, in some circumstances, be one of the more visible and measurable aspects of education. However, the definition of what constitutes as knowledge and the varying types of knowledge which are prevalent in different disciplines make the holistic goal of learning a complex philosophical and epistemological agenda. Considering that different types of knowledge are emphasised more than others in different subject areas (O'Donnell and Henriksen 2002), such as propositional knowledge in science and technological knowledge in technology (de Vries 2016), there is a need to consider the potential educational implications within subjects resulting from a prevalence of certain knowledge types. One potentially auspicious context to examine the prevalence of knowledge types is in the difference between scientific and technological knowledge. While the development of scientific and technological knowledge is related, there are many differences such as the normativity, non-propositionality and context-specificity of technological knowledge (de Vries 2016). While scientific knowledge is universal, associated with truths and has relatively clear distinctions in the boundaries of knowledge between the different scientific sub-disciplines such as physics, chemistry and biology, explicit knowledge within technology education is difficult to define (McCormick 1997, 2004; Kimbell 2011; Williams and Williams 1997; Williams, Iglesias, and Barak 2008; de Vries 2016). These differences undoubtedly influence how both types of knowledge are taught and learned and it is therefore paramount to examine the effect this can have on students. This article specifically focuses on the educational implications of technological knowledge in the context of the variability in explicit knowledge which is considered central to the discipline. However, this differentiating characteristic between technological and scientific knowledge means scientific knowledge is regularly discussed throughout the article in a comparative sense. To explore the educational implications of technological knowledge, data were gathered relative to technology education in Ireland. The rationale for this is described later in the article. Additionally, while the context of the data is Irish, parallels are drawn with other countries to provide an international context for the study.

The nature of knowledge

In order to examine the educational implications of technological knowledge, there is a need to delineate between the different types of knowledge which may be espoused within subjects or within particular tasks characteristic of different subjects. Aristotle (2000) described three types of knowledge as episteme, techne and phronesis. Episteme, which is often described as scientific knowledge (Lally et al. 2012), is associated with universal laws and aspires to be context invariant (Frank 2004). Techne involves art, craft and skill (Wiliam 2008), and relates to what is now called technology (Frank 2004). Frank (2004, 221) describes the relationship between episteme and techne as being that 'techne teaches how to craft, and episteme teaches the laws that govern what is crafted'. de Vries (2016) provides a similar description of the differences between scientific and technological knowledge noting that when scientific knowledge crosses the boundary into application, a transition into technology has occurred. It is clear that episteme can exist without techne, however much of techne is dependent on episteme. Finally, phronesis relates to prudence and is often described as a form of 'practical wisdom' (Millo and Schinckus 2016, 124), adding an ethical dimension to knowledge (Hughes 2001). Frank (2004, 221), continuing the craft-orientated narrative, describes phronesis as the knowledge of 'what we ought to craft'. While all three are considered to be intellectual virtues (Aristotle 2000), phronesis transcends episteme and techne as it concerns acting rationally in variable situations (Wiliam 2008).

As the discourse pertinent to knowledge in education evolved, new terminology emerged, particularly in the differentiation between scientific and technological knowledge. One of the more popular divisions of knowledge was put forward by Ryle (1949) where he described the separate knowledge types of knowing that and knowing how, where knowing that is propositional knowledge and knowing how is associated with skills. The validity of this dichotomy has been the subject of significant philosophical debate. For example, Stanley and Willlamson (2001) argue that knowing how is really a form of knowing that while Hetherington (2011) argues the opposite suggesting that knowing that is really a form of knowing how. However, through an analysis of Gettier-cases (Gettier 1963), Norström (2015) presents an argument stating that, at least in terms of technology education, the dichotomy of knowing how and knowing that holds true. While this is more contemporary terminology, there is a significant degree of similarity between Ryle's (1949) knowing that and episteme, and between his concept of knowing how and techne.

Considering the constructs of episteme, techne and phronesis as the three primary categories of knowledge, there is a need to examine each more closely to facilitate a more nuanced critique of the educational implications of knowledge. There are many taxonomies of specific knowledge types (de Jong and Ferguson-Hessler 1996; Alavi and Leidner 2001; Gorman 2002; Huang and Yang 2009), and the philosophical debate associated with qualifying a knowledge taxonomy persists in epistemological research. However, prevailing types of knowledge can be extrapolated from these taxonomies which can give further clarity to techne, episteme and phronesis. In particular, these taxonomies put forward new terminology for Ryle's (1949) ideas of knowing how and knowing that. They also allow this remit of knowledge types or ways of knowing to be extended as more have since been described. These knowledge types include:

- Declarative knowledge, synonymous with Ryle's (1949) knowing that and sometimes referred to as knowing what (Gorman 2002), is the knowledge of terminology and facts (Huang and Yang 2009).
- Conceptual knowledge is related to declarative knowledge (Gibson 2008) in that it is associated with relationships between pieces of knowledge (McCormick 1997).
- Procedural knowledge, synonymous with Ryle's (1949) knowing how, is knowledge about procedures, actions and steps (Pirttimaa and Husu 2017) which Anderson (1983) notes is initially encoded as declarative knowledge before translating into procedural knowledge.
- Conditional knowledge (Alavi and Leidner 2001), strategic knowledge (Gibson 2008) or judgement (Gorman 2002), also described as knowing when, relates knowledge of conditions and what to do in certain situations.

- Causal knowledge (Alavi and Leidner 2001) or wisdom (Gorman 2002), also described as knowing why, describes a knowledge of why certain actions should be taken both from a moral or ethical perspective and based on their causal effects.

Building on these types of knowledge, there are many other qualities of knowledge including levels of knowledge, the structure of knowledge, if knowledge is automated or non-automated, the modality of knowledge and if knowledge is domain general or domain specific (de Jong and Ferguson-Hessler 1996). Another particularly important quality of knowledge in supporting its classification is whether knowledge is explicit or tacit. Collins (2010, 4) describes tacit knowledge as 'knowledge that is not explicated'. However, he further describes a contention with the term tacit in that the differentiation needs to be made between knowledge which 'is not' and which 'cannot' be explicated as there is a significant difference between these cases. Collins (2010) ultimately notes that Polanyi's use of the term tacit describes knowledge which cannot be explicated and defines explicit knowledge as the opposite or knowledge which can be explicated. Providing further clarity, Polanyi describes the relationship between explicit and tacit knowledge saying that:

> Now we see tacit knowledge opposed to explicit knowledge; but these two are not sharply divided. While tacit knowledge can be possessed by itself, explicit knowledge must rely on being tacitly understood and applied. Hence all knowledge is either tacit or rooted in tacit knowledge. A wholly explicit knowledge is unthinkable. (Polanyi 1969, 144)

Perhaps the most common example used to differentiate between explicit and tacit knowledge is that of riding a bicycle (e.g. Norström 2014). To describe the components of a bicycle and the actions involved in riding a bicycle such as pedalling is possible as this is explicit propositional knowledge, however the knowledge of how to balance while riding a bicycle is impossible to describe without resulting to superficial explanations. It is also impossible to teach this knowledge through direct information transmission approaches. Instead, the feeling of how to balance must be learned through experience. This is a particularly important distinction of knowledge types for technology education as much of the procedural knowledge involved in technological craft is tacit in this way (Leonard and Sensiper 1998; Norström 2014). Gorman (2002, 228) offers a descriptive overview of the four types of knowledge (knowing that or knowing what, knowing how, knowing when and knowing why), providing explicit and tacit examples of each, and also refers to kinaesthetic knowledge as a specific tacit form of procedural knowledge alongside 'hands-on' knowledge and heuristics.

Technological capability as technological knowledge

Considering these types of knowledge in the context of technology education initially requires a broader examination of what the discipline aims to espouse within students. The overall aim of technology education is regularly acknowledged internationally to mean the development of technological capability (Black and Harrison 1985; Kimbell 1994; Norman 1998; Davies and Rogers 2000; Tairab 2001; Shaw 2002; Gibson 2008; Rauscher 2011; Liou 2015). Due to its subjectivity, traditionally it has been difficult to offer an explicit classical definition for the concept of technological capability (Gagel 2004) which has resulted in many definitions now existing in the pertinent literature. Black and Harrison (1985) define technological capability as being able 'to perform, to originate, to get things done, to make and stand by decisions' (Black and Harrison 1985, 6). At post-primary level in Ireland, a practical perspective of the manifestation of developing technological capability in education is provided. It is defined as having 'understanding of appropriate concepts and processes; skills of design and realisation; the ability to apply knowledge and skills by thinking and acting confidently, imaginatively, creatively and with sensitivity; [and] the ability to evaluate technological activities, artefacts and systems critically and constructively' (e.g. DES 2007a, 2007b, 2). This definition is also very similar to the definition adopted in Scottish post-primary technology education curricula (Scottish 1996). While these definitions provide valuable insight into what it means to be technologically capable, the most widely accepted perspective of technological capability is the definition provided by Gibson (2008). Gibson's (2008) model describes technological capability as the unison of skills, values and problem solving in a three-set Venn diagram underpinned by appropriate conceptual knowledge. As this is the most contemporary and widely accepted perspective, it is important to examine how this model relates to knowledge to determine how technological knowledge manifests within education.

Knowledge is clearly apparent in Gibson's (2008) model. Described as conceptual knowledge which is 'both unique to technology and imported from other areas' (p. 11) and based on Gibson's (2008) description of the relationship between declarative and conceptual knowledge, this appears to represent episteme and accounts for the knowing that type of knowledge. Such a consideration can be seen in the English national curriculum for design and technology education where pupils are expected to 'understand and use the properties of materials and the performance of structural elements to achieve functioning solutions' (Department for Education 2013, 3). This can also be seen in the technology education curriculum in New Zealand which highlights how 'technology makes enterprising use of knowledge, skills and practices for exploration and communication, some specific to areas within technology and some from other disciplines' (Ministry of Education 2017, 1). Skills are positioned within the conceptual knowledge aspect of the model. Gibson (2008) notes that while some people consider knowledge and skills as separate yet interactive, others acknowledge skills as a form of procedural knowledge (Mason and Houghton 1997, 2002; McCormick 2004; Stevenson 2004). However, as previously discussed, techne describes knowledge of skills, craft and art. Gibson (2008, 9) also notes that an attainment target for technology and design called 'capability' describes the skills central to technology education as being 'intellectual, physical and communication skills'. Acknowledging the declarative knowledge elements in each, as Gibson (2008) himself notes that the intellectual skills broadly equate to procedural knowledge, physical skills being considered a form of procedural knowledge although with perhaps a more tacit element (Leonard and Sensiper 1998; Norström 2014), and communication skills also being acknowledged as a culmination of knowledge types (Leonard and Sensiper 1998), it is arguable that the skills element of Gibson's (2008) model represents the knowing how aspect of knowledge. A third element of Gibson's (2008) model refers to values with Gibson noting that skills and knowledge must be applied using appropriate values. What Gibson (2008) considers to be values is arguably phronesis. Firstly, Gibson acknowledges Riggs (1995) position that value-based decisions must be knowledge based. Additionally, a person's values don't make them more or less capable as they are implicit and subjective. Values may impact the decisions a person makes in a specific context but choosing one approach does not indicate a lack of capability in another. The recognition of values as an element of capability is made clearer when considering how Gibson describes its position in his model. When describing the enactment of values, Gibson (2008) conflates the term with ethics. For example, an action based on values alone is described as a 'purely theoretical or academic exercise: for example, an essay based on ethical issues' while the synthesis of skills and values is described as 'purely craft level but within an ethical framework' (p. 12). It appears as though Gibson (2008) is describing what was previously described as phronesis or practical wisdom, the knowing why type of knowledge. Finally, Gibson's (2008) model contains the element of problem solving. While undoubtedly important in technology education (Williams and Williams 1997; Williams, Iglesias, and Barak 2008), it is difficult to position between knowledge, skills and values, as while a person can have knowledge, skills and values, they cannot have problem solving. Problem solving is an action, one where knowledge, skills and values can be evidenced within. While Gibson (2008) is undoubtedly describing a person who is good at problem solving, this requires them to have sufficient knowledge relative to the problem. What the acknowledgement of the problem-solving dimension adds however is a context exemplifying that conditional or strategic knowledge, or the knowing when type of knowledge, is important in technology education. Perhaps what is considered to be technological capability is better expressed as technological knowledge, or knowledge (a synthesis of knowing that, how, why and when) of and in a technological context.

While this argument doesn't provide a clear insight into the explicit aspects of technological knowledge in terms of its content, it does serve to illustrate that being capable in a discipline is largely associated with the acquisition of knowledge relative to that discipline. This is perhaps possible to explicate more in some disciplines such as science, and is perhaps more relative in others such as technology. This challenge is highlighted in an analysis of the technology education curricula of Australia, England, France, The Netherlands, Sweden, and the United States conducted by Rasinen (2003) where it was found that while the curricula of these countries demonstrated a philosophical coherency, the most significant divergence was observed in the structure of the curricula. What is therefore important to consider is the nature or content of the knowledge typically found in each type of knowledge in a discipline and if and how a prevalence of certain knowledge types exist in certain disciplines. Based on this, it is also critical to consider how certain subjects form part of a larger whole school curriculum. Considering the agenda of post-primary education being to foster the general holistic development of students, from this perspective it is paramount that a broad range of knowledge types are engaged with.

Research questions

Considering the generally accepted aim of technology education is the development of technological capability, which is arguably synonymous with technological knowledge, the current study aimed to examine the potential impact of technological knowledge in education. To do this, technology education was investigated within the Irish education system as it is nationally assessed through standardised examinations created by a government body known as the State Examination Commission (SEC). This entire national assessment is known as the Leaving Certificate. Therefore, to examine technological knowledge in this context, the following research questions (RQ) guided the methodological design.

RQ1. What is the association between performance in individual subjects, particularly technology subjects, and performance in the Leaving Certificate?

RQ2. What is the association between the number of technology subjects studied and performance in the Leaving Certificate?

RQ3. What effect does studying an increased number of technology subjects have on performance in the Leaving Certificate?

RQ4. What effect does studying an increased number of technology subjects have on performance in technology subjects and non-technology subjects?

Method

Approach

In order to examine technological knowledge, a measure which represents the entire remit of technology education was needed. As discussed, in order to achieve this, data from the Irish education system were used. At post-primary level in Ireland, all teaching is delivered by subject specialists and there are strict regulations (such as pertinent third-level education and a probation period) in place concerning the criteria which people must meet in order to be allowed to teach. At the end of post-primary education, at approximately the age of 18, pupils in the Irish education system take a standardised national assessment known as the Leaving Certificate. This assessment is considered to be a high stakes assessment as it serves as the country's primary matriculation system for entry into third level education. The subjects of Mathematics, English and Irish are considered to be compulsory as they are typically required to meet university course entry requirements, and with these pupils select from other optional subjects based on the range provided by their school. Typically this will include a European language and approximately three or four more subjects. Pupils can study any subject at either Higher level or Ordinary level with the exception of the Leaving Certificate Vocational Programme (LCVP) which is provided at a Common level for all pupils. A Foundation level is also provided in Mathematics and Irish. The difference between the Higher,Ordinary and Foundation level provision of a subject is that as the level of provision is increased, from Foundation level to Higher level, more advanced content is added. Each topic is addressed at each level, but only Higher level includes all content associated with each topic (as specified within the subject syllabi) It is therefore arguable that a Higher level examination is more representative of a subject than an Ordinary or Foundation level examination due to the more comprehensive remit of knowledge which is considered within the examination. The Leaving Certificate consists of multiple examinations which represent each subject pupils can study. These examinations are created external to schools by a government body known as the State Examination Commission (SEC). Each examination is designed to assess the aims and learning objectives of each subject with some consisting entirely of a paper and pencil based summative examination and others, where appropriate, consisting of a project or practical element as well. The format of each exam is designed relative to the knowledge type it must assess. Pupils receive a standardised number of points relative to their performance in an examination allowing subjects to be compared (Table 1). Pupils' total scores are formulated as the combined sum of their six highest results from all of their subjects.

In addition to the validity of the data provided by the external moderation and standardisation of Leaving Certification examinations, a five year cohort study was conducted between 2010 and 2014 to gather longitudinal data. This further increased the

Table 1. Leaving certificate grade to points conversion table prior to 2017.

Grade	Higher level points	Ordinary level points	Foundation level points	Maths higher level points	LCVP	
					Grade	Points
A1	100	60	20	125	Distinction	70
A2	90	50	15	115	Merit	50
B1	85	45	10	110	Pass	30
B2	80	40	5	105		
B3	75	35	–	100		
C1	70	30	–	95		
C2	65	25	–	90		
C3	60	20	–	85		
D1	55	15	–	80		
D2	50	10	–	75		
D3	45	5	–	70		
E	–	–	–	–		
F	–	–	–	–		
NG	–	–	–	–		

Note. The grading system changed in 2017 however as this does not affect the data for this study it is not represented here.

Table 2. National statistics of subject engagement and grade dispersion (%) for the recognised compulsory subjects, technology subjects and primary science subjects from 2010 to 2014 of the Irish Leaving Certificate examination compiled from the State Examination Commission (2018).

Subject	Level	*N*	A1–A2	B1–B3	C1–C3	D1–D3	E–NG
Irish	H	79,743	14.62	36.98	34.70	12.90	0.76
Irish	O	120,399	3.14	32.14	39.72	20.46	4.50
Irish	F	21,078	6.12	31.70	39.42	18.82	3.94
English	H	167,151	10.06	26.80	39.66	21.92	1.52
English	O	89,408	7.86	30.44	38.70	19.58	3.46
Mathematics	H	55,096	11.80	30.90	34.90	19.06	3.28
Mathematics	O	173,918	7.92	28.02	31.12	23.58	9.38
Mathematics	F	28,946	7.18	33.04	35.76	18.44	5.64
Physics	H	24,643	20.24	28.28	24.82	19.12	7.48
Physics	O	8,616	15.38	30.98	26.28	16.86	10.54
Chemistry	H	33,257	20.82	29.08	24.16	17.44	8.46
Chemistry	O	6,814	8.18	23.58	28.56	23.42	16.34
Biology	H	114,262	15.66	27.18	27.50	21.64	8.10
Biology	O	40,325	2.06	21.08	36.56	27.66	12.66
Engineering	H	19,553	9.82	32.58	34.84	19.36	3.42
Engineering	O	5,457	2.04	23.38	39.64	26.90	8.04
Construction	H	34,115	7.94	32.94	36.24	19.30	3.58
Construction	O	8,360	0.46	14.46	39.44	32.86	12.84
Technology	H	4,079	14.20	36.06	30.60	14.58	4.56
Technology	O	679	5.04	25.36	28.52	25.52	15.58
DCG	H	20,145	14.32	33.82	32.32	16.44	3.14
DCG	O	7,576	7.36	32.18	33.38	17.84	9.16

Note: The total population of pupils who engaged with the Leaving Certification examination from 2010 to 2014 was 268,103. H = Higher level. O = Ordinary level. F = Foundation level.

representativeness of performance scores in each subject as the longitudinal data would decrease any potential biases in individual examinations should any have occurred during the years of data collection. In order to provide national level context, Table 2 provides statistics pertaining the subject uptake and grade dispersion of the four technology subjects considered in this paper (Construction Studies, Engineering, Technology, and DCG). Additionally, to allow for comparisons to be made, the same statistics are provided for the

Table 3. Cohort demographic information.

School	Population	Gender	N 2010	2011	2012	2013	2014	Total
SCH01	≈400	Male	76	83	40	68	56	323
SCH02	≈350	Mixed	53	89	48	77	112	379
SCH03	≈700	Mixed	84	63	64	64	90	365
SCH04	≈900	Mixed	145	135	142	126	146	694

three primary science subjects (Physics, Chemistry and Biology), and the recognised compulsory subjects (Irish, English and Mathematics).

Considering the Irish educational system as a context has additional merit as the subject syllabi for the science and technology subjects present explicit details concerning the knowledge and skills the subjects aspire to espouse (DES 1999a, 1999b, 2001, 2007a, 2007b). This means the nature of knowledge in these subjects can be further examined to clarify more explicitly what the subjects aspire to espouse.

Participants

To represent a cross-sectional view of the system, schools form urban, suburban and rural regions in Ireland were included. As this study placed a particular focus on technology education, in order to be included a school had to offer three of the four technology subjects provided in the Irish post-primary national curriculum; Design and Communication Graphics (DCG), Construction Studies and Engineering. The fourth subject, Technology, was not mandated in the inclusion criteria due to its low provision nationally. Four schools provided anonymised data of Leaving Certificate performance across five years (2010-2014 inclusive) giving a total sample of 1,761 pupils. Considering that the total population was 268,103 (Table 2), the results from this sample have a margin of error of 2.33% at the 95% confidence level suggesting a high degree of representation. Table 3 provides a detailed description of schools demographic information and the number of pupils results provided from each.

Results

Prior to analysing the data in accordance with the previously described research questions, a correlation analysis was conducted exclusively on the four technology subjects to ensure sufficient similarity to infer that in general they address a similar educational aim. Only performance at Higher level was considered for this analysis based on the better representation of the subjects this examination is argued to offer. The results are presented in Table 4 and illustrate statistically significant correlations between all technology subjects, except between Engineering and Technology as no pupil studied both simultaneously. The strength of the correlations ranged from moderate ($r = .588$) to very strong ($r = .918$). These results suggest a common element within these subjects which, based on the pertinent literature, can be at least in part interpreted as technological knowledge.

Following the establishment of a commonality between the technology subjects, data analysis was conducted to answer the first research question which asked what the association between performance in individual subjects, particularly technology subjects, and performance in the Leaving Certificate is. The total sample ($n = 1761$) was divided into

Table 4. Correlation matrix of performance in higher level technology subjects.

		Engineering	Construction	Technology	DCG
Engineering	*r*	–			
	N				
Construction	*r*	.768**	–		
	N	64			
Technology	*r*		.918**	–	
	N		34		
DCG	*r*	.691**	.702**	.588*	–
	N	40	90	18	

**Correlation is significant at the 0.01 level (2-tailed).; *Correlation is significant at the 0.05 level (2-tailed).

Table 5. Associations (χ^2) and effect sizes (Cramer's *V*) between subject uptake and quartiles determined from total Leaving Certificate points (Higher level).

Subject	*n*	χ^2	*V*	*p*	Q1 (%)	Q2 (%)	Q3 (%)	Q4 (%)
Accounting	155	69.046	.198	.000	3.2	25.2	22.6	49.0
Ag. Science	510	72.770	.203	.000	11.2	30.6	31.8	26.5
Applied Maths	42	61.541	.187	.000	2.4	2.4	19.0	76.2
Art	213	14.530	.091	.002	18.3	31.0	31.5	19.2
Biology	798	222.389	.355	.000	7.9	27.6	32.0	32.6
Business	359	82.475	.216	.000	6.1	29.0	32.3	32.6
Chemistry	243	236.220	.366	.000	3.3	11.5	21.4	63.8
Construction	334	41.379	.153	.000	29.6	29.6	29.0	11.7
Czech	2	1.987	.034	.575	–	50.0	50.0	–
DCG	185	16.715	.097	.001	14.1	31.9	31.4	22.7
Economics	204	33.782	.139	.000	8.8	25.5	30.9	34.8
Engineering	200	15.850	.095	.001	25.0	35.0	23.0	17.0
English	1106	618.960	.593	.000	7.0	22.8	32.2	38.1
Estonian	1	3.107	.042	.375	100.0	–	–	–
French	329	193.604	.332	.000	2.1	16.4	31.9	49.5
Geography	751	106.060	.245	.000	14.0	31.0	32.2	22.8
German	237	89.812	.226	.000	3.4	23.2	29.1	44.3
History	275	43.164	.157	.000	10.2	24.4	29.8	35.6
Home Economics	200	32.321	.135	.000	16.0	25.5	40.5	18.0
Irish	560	492.980	.529	.000	2.7	12.5	30.2	54.6
Japanese	1	2.968	.041	.397	–	–	100.0	–
Lithuanian	1	3.004	.041	.391	–	100.0	–	–
Mathematics	430	470.571	.517	.000	1.2	10.0	27.2	61.6
Music	138	53.918	.175	.000	8.7	12.3	32.6	46.4
Physchem	65	10.720	.078	.013	23.1	40.0	24.6	12.3
Physics	211	125.212	.267	.000	4.7	13.7	28.0	53.6
Polish	19	7.830	.670	.050	47.4	31.6	10.5	10.5
Portuguese	1	3.107	.420	.375	100.0	–	–	–
Religion	62	19.653	.106	.000	4.8	19.4	33.9	41.9
Russian	1	2.932	.041	.402	–	–	–	100.0
Spanish	162	107.036	.247	.000	2.5	11.7	32.1	53.7
Technology	48	2.594	.380	.459	22.9	29.2	31.3	16.7

quartiles relative to total performance in the Leaving Certificate (Q1 ≤ 255, Q2 256–360, Q3 361–435, Q4 362–600). A chi-squared test was conducted to examine the associations between individual subject uptake and Leaving Certificate performance based on distributions across quartiles. The analysis was conducted for all subjects at all levels and revealed a large number of statistically significant associations. The results of this analysis for Higher and Ordinary level are presented in Tables 5 and 6, respectively, with effect sizes denoted by Cramer's *V*.

Table 6. Associations (χ^2) and effect sizes (Cramer's *V*) between subject uptake and quartiles determined from total Leaving Certificate points (Ordinary, Foundation and Common level).

Subject	n	χ^2	*V*	*p*	Q1 (%)	Q2 (%)	Q3 (%)	Q4 (%)
Accounting	41	31.692	.134	.000	58.5	26.8	12.2	2.4
Ag. Science	117	175.290	.315	.000	72.6	23.9	2.6	0.9
Applied Maths	2	2.038	.034	.565	50.0	–	50.0	–
Art	76	213.636	.348	.000	94.7	2.6	2.6	–
Biology	197	338.344	.438	.000	75.1	22.8	1.5	0.5
Business	109	183.063	.322	.000	76.1	22.0	1.8	–
Chemistry	23	14.156	.090	.003	52.2	30.4	17.4	–
Construction	32	101.196	.240	.000	100.0	–	–	–
DCG	40	90.191	.226	.000	87.5	12.5	–	–
Economics	85	87.909	.223	.000	61.2	32.9	5.9	–
Engineering	17	53.298	.174	.000	100.0	–	–	–
English	626	630.318	.598	.000	55.1	28.9	12.6	3.4
French	190	19.979	.107	.000	26.3	35.3	24.2	14.2
Geography	179	462.879	.513	.000	89.4	10.6	–	–
German	97	35.654	.142	.000	47.4	26.8	15.5	10.3
History	67	110.598	.251	.000	77.6	16.4	4.5	1.5
Home Economics	43	93.318	.230	.000	86.0	14.0	–	–
Irish	861	156.239	.298	.000	25.0	34.5	26.9	13.6
Irish (F)	120	225.637	.358	.000	80.0	17.5	2.5	–
LCVP (C)	562	49.437	.168	.000	28.1	32.4	22.8	16.7
Maths	1159	235.561	.366	.000	23.5	33.4	27.6	15.5
Maths (F)	157	457.644	.510	.000	94.3	3.8	1.9	–
Music	10	23.766	.116	.000	90.0	10.0	–	–
Physchem	19	38.621	.148	.000	84.2	15.8	–	–
Physics	58	27.872	.126	.000	48.3	31.0	17.2	3.4
Religion	5	8.962	.710	.030	80.0	20.0	–	–
Spanish	43	11.410	.081	.010	27.9	44.2	16.3	11.6
Technology	7	21.821	.111	.000	100.0	–	–	–

Note: All subjects are Ordinary level unless otherwise denoted as Foundation level (F) or Common level (C).

The analysis proceeded with the extraction of only the statistically significant associations and to examine the top (Q4) and bottom (Q1) quartiles. This was done to get a clearer insight into how individual subject uptake in general can affect overall educational performance. Figures 1 and 2 illustrate this data for the subjects at Higher and Ordinary level. The individual subjects are ordered based on the magnitude of variance between the percentage of participating pupils in Q1 and Q4. For Higher level, the subjects with the largest percentage of pupils in the top quartile include subjects concerning mathematics, foreign languages and the natural sciences. This is also reflected in the Ordinary level subjects. In contrast, for Higher level, the subjects with the largest percentage of pupils in the bottom quartile include the technology subjects, Art, Home Economics and Physchem. Again, this result is similar at Ordinary level. These results indicate that pupils studying subjects with more of a practical or project focus, or subjects which arguably have more of a focus on techne in their core knowledge base, are less likely to be in Q4 and more likely to be in Q1 than pupils engaging with subjects which arguably focus more on propositional knowledge or episteme, evidencing that they perform significantly worse academically in terms of overall points acquired.

Building on this, the second research question asked what the association between the number of technology subjects studied and performance in the Leaving Certificate is. A chi-squared test of independence was performed to examine the relationship between the number of technology subjects studied and being in a specific quartile. The relationship between these variables was significant, χ^2 (9, $n = 1761$) = 59.099, $p < .001$, $V = .106$. The complete distribution is shown in Figure 3. These results clearly illustrate that the more

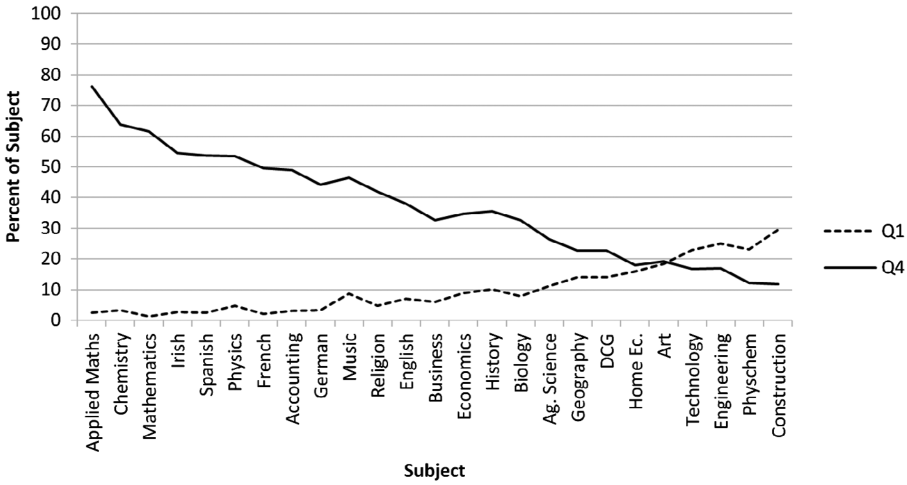

Figure 1. Statistically significant distributions between Q1 and Q4 for Higher level subjects. Subjects are ordered (left to right) based on the variance between the percentage of pupils in Q1 and Q4.

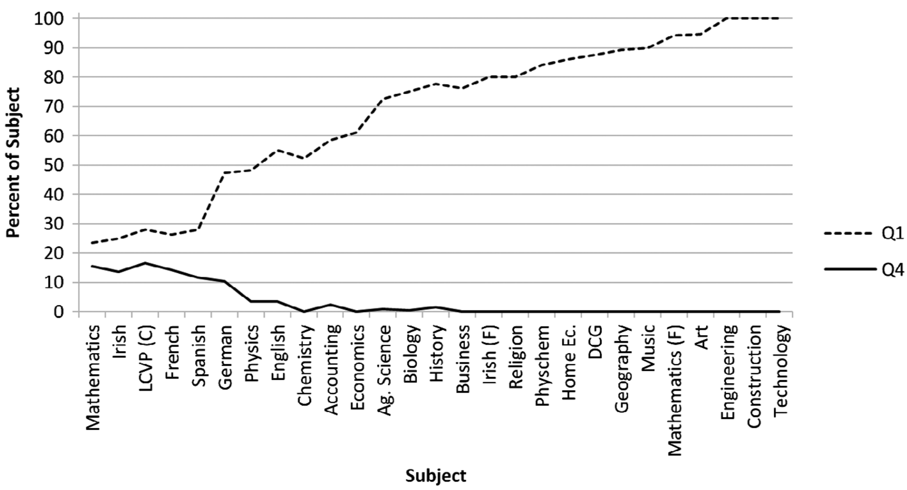

Figure 2. Statistically significant distributions between Q1 and Q4 for Ordinary, Foundation (F), and Common (C) level subjects. Subjects are ordered (left to right) based on the variance between the percentage of pupils in Q1 and Q4.

technology subjects which are studied, the increased likelihood there is of being in a lower quartile.

The third research questions strongly relates to the second and asks to what effect does studying an increased number of technology subjects have on performance in the Leaving Certificate. A one-way ANOVA was conducted to compare the effect that the number of technology subjects studied had on the total Leaving Certificate points attained for the conditions of studying one, two or three technology subjects. A statistically significant difference was found between the three conditions, $F(3, 1757) = 7.956$, $p < .001$. A Tukey's HSD post-hoc test indicated that the average points attained by the pupils studying no

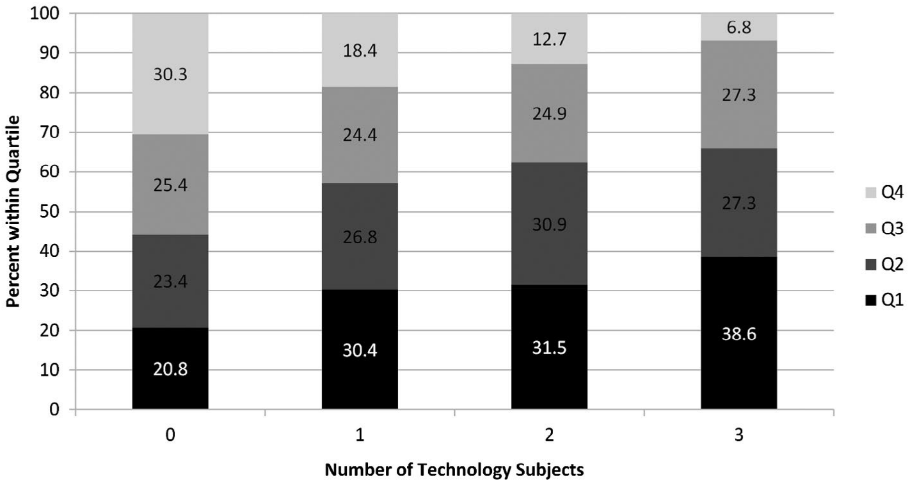

Figure 3. Distribution of results between quartiles based on the number of technology subjects studied.

technology subjects was significantly different than the average points attained by pupils studying one technology subject, $p < .001$. No other statistically significant differences were observed between the other groups however there was a large variance in mean performance between the group studying no technology subjects ($M = 350.00$, SD = 131.89) and the groups studying either one ($M = 315.74$, SD = 132.12), two ($M = 322.56$, SD = 106.04), or three ($M = 319.72$, SD = 99.28) technology subjects. These results suggest that studying no technology subjects is statistically significantly better than studying one, and while not statistically significant it is also better than studying more than one. However, if a pupil is interested in studying technology, it is more beneficial from the perspective of overall performance to study multiple technology subjects although this is not statistically significant.

The final research question sought to answer to what effect does studying an increased number of technology subjects have on performance in technology subjects and non-technology subjects. Paired samples t-tests were performed to determine if there was a statistically significant difference between the average score attained across all technology subjects taken and the average score across all non-technology subjects taken. Three t-tests were performed to examine the three different conditions of pupils taking one, two, or three technology subjects. Where pupils studied one technology subject ($n = 365$), a statistically significant difference was found between their technology subject score ($M = 65.19$, SD = 21.64) and the average score for their other five subjects ($M = 49.43$, SD = 23.13); $t(364) = -21.511$, $p < .001$. Where pupils studied two technology subjects ($n = 162$), a statistically significant difference was found between the average score for their technology subjects ($M = 67.45$, SD = 16.54) and the average of their other four subjects ($M = 46.24$, SD = 19.92); $t(161) = -21.492$, $p < .001$. Finally, where pupils studied three technology subjects ($n = 36$), a statistically significant difference was found between the average score for their technology subjects ($M = 64.40$, SD = 16.76) and the average of their other three subjects ($M = 41.29$, SD = 18.14); $t(35) = -15.817$, $p < .001$. A one-way ANOVA was conducted to compare the variances in average performance in technology subjects between the groups who studied one, two or three of the subjects. No statistically significant difference was found between the three groups in terms of their average score in technology subjects, $F(2, 560) = .810$, $p = .445$. A final one-way ANOVA was conducted to compare the variances in average performance in non-technology subjects between the groups who studied one, two or three of the technology subjects. No statistically significant difference was found between the three groups in terms of their average score in technology subjects, $F(2, 560) = 2.976$, $p = .052$. These results illustrate that when studying one, two or three technology subjects, the average result of those subjects was always statistically significantly greater than the average result of the pupils non-technology subjects. However, while there was no statistically significant difference or trend in average technology performance relative to the number of technology subjects studied, a non-statistically significant trend emerged showing reduced performance in non-technology subjects relative to an increase in the number of technology subjects studied.

Discussion

The results of this study demonstrate significant differences in overall performance between pupils engaging in technology subjects and subjects such as mathematics, foreign languages and the natural sciences. While the technology subjects clearly emphasise techne (de Vries 2016), the subjects of mathematics, foreign languages and the natural sciences have more of a focus on episteme (O'Donnell and Henriksen 2002). This can be seen both in the varying magnitudes of knowledge and skills in the sciences and technological subjects in the Irish curriculum and how knowledge and skills are represented in these subjects (e.g. DES 1999a, 1999b, 2001, 2007a, 2007b). In the technology subjects the 'acquisition of manipulative skills is an important component' (e.g. DES 2007a, 2007b, 2) and is considered to be core knowledge. Similarly there is an emphasis on skills 'concerning the production of useful artefacts and systems' (p. 2). In the science subjects the construct of skills refers to actions such as being able to perform experiments safely and co-operatively, to measure physical quantities in the appropriate SI units, to select and manipulate suitable apparatus to perform specified tasks, to make accurate observations and measurements, and to interpret experimental data and assess the accuracy of experimental results (e.g. DES 1999a, 1999b). It is clear that skills in technology education refer to procedural knowledge, much of this being tacit and reflecting techne, while in the science subjects, skills appear to represent methods for acquiring more propositional knowledge, reflecting episteme. A similar distinction is clear in relation to the consideration of knowledge within the sciences and technological subjects. Within the technology subjects, acquiring knowledge is considered important, but larger emphasis is given to its integration and application in the context of each subject area (e.g. DES 2007a, 2007b). In contrast, in the science subjects the syllabi objectives are broken into the five sections of knowledge, understanding, skills, competence and attitudes (e.g. DES 1999a, 1999b). There is little mention of pupils applying knowledge outside of the conduction of experiments to acquire further scientific knowledge. Instead, when discussing the application of knowledge the emphasis is on pupils learning where scientific knowledge has and can be applied, rather than on their own personal application. The boundary of knowledge is also clearly distinct across each of the science subjects, a characteristic not fully shared in the technology subjects due to the substantial overlap in pertinent knowledge. These distinctions appear to be reflected internationally (e.g. Rasinen 2003) however due to the context specificity of the data, the results reported in the paper do not allow for international generalisation. However it would be of interest to determine the educational implications of knowledge types in a wider range of contexts.

There are implications for both general education provision and individual pupils based on these results however these are largely linked. From the perspective of a pupil, the results of this study appear to suggest that engaging with technology subjects is not strategically beneficial if they have an agenda of attaining as many points as possible. However, this is not necessarily true. This argument is more complex than simply stating that studying technology subjects has negative implications. When considering the results illustrating that for pupils who do study technology subjects those subjects are statistically more likely to be their best performing subject, it is possible that it may have been a beneficial subject for those pupils as they may have had a particular aptitude in that area. Pupils may also have an interest in this area and by selecting other subjects which they have less of an interest in based on a points agenda is likely to high significant negative implications for the pupil in terms of general engagement.

The data could also be construed to infer that pupils who engage with the technology subjects are in some way less intelligent than those who engage with the science subjects. However this is unfair to suggest for many reasons and the data does not have the capacity to tell this. One such reason is that post-primary education in Ireland is divided into two stages, the Leaving Certificate being the second stage, and technology subjects are optional at each stage. Choosing to study certain subjects at the beginning of post-primary education is likely to influence subject choice for the Leaving Certificate. Subject selection is likely to be largely influenced by interest which has a significant relationship with academic performance in that subject (Hulleman and Harackiewicz 2009). Considering the results of this study showing that pupils who studied one or more technology subjects performed best in those subjects, it could be that those pupils had a particularly high interest in the area. Another reason relates to a recent national review of STEM education in Ireland conducted by the STEM Education Review Group (2016, 44) which found that 'students' subject choices are often made to secure maximum points in the Leaving Certificate'. This is likely to be influenced, at least in part, by feedback from peers, family and teachers. It could be the case that technology subjects are considered easier to achieve points in than others creating an appeal for pupils to study them.

One potential explanation for the marked discrepancies between pupils who choose to study technology and pupils who choose to study subjects such as Mathematics, foreign languages and the natural sciences concerns the primary knowledge types of those subjects. Mathematics, Irish and English are recognised as compulsory and studying a foreign language is preferable to satisfy the majority of university entry requirements. These subjects have, to varying degrees, a heavy focus on episteme. If pupils choose to study the natural sciences, more mathematics based subjects or more foreign languages, their learning requirements are heavily focused on the acquisition of propositional knowledge or episteme. Pupils who choose to study the technology subjects or other subjects with more of an emphasis on techne are required to divide their attention between acquiring two different types of knowledge. From an individual development perspective this could be considered an advantage as there is more engagement with a diverse range of knowledge types. From a performance perspective, this could be seen as a disadvantage. By engaging with a broader range of knowledge types, pupils will have less time to develop episteme relating proficiencies. In sharp contrast to a pupil who could select a maximum of three technology subjects resulting in an approximately equal episteme/techne split, a high performing Q4 pupil is more likely to solely select episteme categorised subjects. This could be considered as a systematic implication for general education provision. Considering the differences between episteme and techne, when compulsory subjects focus predominantly on one type of knowledge and there is a possibility to circumvent the other, potentially in favour of attaining points, general educational provision is no longer general. It is therefore possible, in the subsequent progression into third-level education and/or into employment, that while pupils may have attained more points they may have a deficit in knowledge which is critical for many areas of work and study. A systematic solution for this would be to create a balance in compulsory subjects between episteme and techne focused subjects. This would reduce the variance between pupils who do and who do not study technology in terms of overall performance, create a more general and balanced education system and ensure much critical knowledge is made more accessible to pupils. Considering the Leaving Certificate primarily serves as a matriculation system into third-level education, such a change would not disrupt its primary purpose as the capacity to differentiate levels of ability would not be disrupted, but it may make it fairer.

Conclusion

To determine a definitive causal explanation for the results of this study, a number of questions need to be addressed. Firstly, it needs to be identified if there are different cognitive mechanisms utilised in the acquisition of different types of knowledge. Secondly, it needs to be identified if a person can become more efficient at acquiring a specific type of knowledge with increased practice. Finally, it needs to be determined if splitting attention between different types of knowledge has an overall negative effect on knowledge acquisition. While this study cannot answer these questions, it does present significant findings of interest to technology and also science education. Pupils who study technology subjects are likely to find that these are their best subjects in terms of performance. They are also more likely to perform worse overall relative to pupils who study science or other episteme orientated subjects. However, it is unfair to imply that this is due to technology pupils being less intelligent due to many variables influencing subject choice. It is also unfair to infer that choosing to study technology subjects is not strategically beneficial as pupils who choose to study these subjects may have a particular aptitude in this area. Instead, it is likely, considering the process of knowledge acquisition as central to learning and considering the differences in knowledge types between the technology and science subjects, that the variances in knowledge types have significant educational implications and can provide a causal explanation for performance differences between subjects. Therefore, from a general education and systematic perspective, while the results may suggest negative implications stem from studying technology subjects, it would likely be more beneficial to interpret the results as suggesting a need for a compulsory technological component to education instead.

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