Do Investment Traits Intellectual Curiosity and Confidence Predict Academic Performance?

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Abstract

Introductory chapters

This thesis addresses the question, “Do investment traits intellectual curiosity and confidence predict academic performance?” To establish the context for this question, the first three chapters introduce several relevant issues. Chapter 1 provides an historical account of intelligence research, especially of Cattell’s identification of fluid and crystallised abilities, and his “investment theory” to explain their relationship. It also surveys Ackerman’s PPIK (Process, Personality, Interests, and Knowledge) theory of adult intelligence—also an investment theory—and considers whether there is sufficient evidence to continue researching intellectual curiosity (IC) within the investment framework. Important within investment theory are so-called “investment traits”—including IC—that determine where and how people apply their cognitive abilities. Chapter 2 introduces a second tradition of curiosity research, starting with Sokolov’s research on the “orienting reflex” and finishing with Mussel’s Intellect framework. It is argued that, despite their distinct histories, these approaches overlap substantially, and that this overlap has implications for how the relationship between intelligence and curiosity is to be understood. Finally, Chapter 3 introduces intelligence and personality as predictors of academic performance (AP), and introduces cognitive confidence as a potential investment trait that also predicts AP.

Exegesis

Chapter 4 provides an exegesis of the four studies that were conducted to assess the question of this thesis, and that are reported in Chapters 5–8. Study 1 assessed the contents of several different scales of IC, and concluded that despite their substantial

overlap, each scale measured a different profile of factors. Study 2 assessed the incremental validity of IC and confidence above intelligence and personality for predicting AP, and could not find evidence for this. Study 3 assessed a novel approach to testing investment theory in adults, and found that confidence (but not IC) predicted variance above Gf in the measure of Gc. Moreover, this study assessed whether reading habits should be incorporated within Mussel's Intellect framework, and concluded that this was not necessary. Lastly, Study 4 involved a critical analysis of von Stumm, Hell, et al. (2011)—who argued that IC is the "third pillar" of academic performance above cognitive ability and Conscientiousness—and argued that several issues call into question this broad conclusion.

Conclusions

Chapter 9 interprets these four studies in the broader context introduced in Chapters 1–3, and provides several conclusions. Concerning the thesis question, it is concluded that although there is substantial evidence for the predictive validity of IC and confidence for AP, the evidence for their incremental validity is mixed and cannot be asserted broadly with certainty. Concerning investment traits IC and confidence, it is concluded that the importance of IC may have been overestimated, whereas the importance of confidence may have been underestimated. And it is also concluded that investment theory needs to be revised substantially because of challenges to several predictions that follow from it. Following this, potential follow-up studies are outlined that potentially would help to resolve several outstanding issues in this domain. Finally, a concluding statement suggests that, despite traditionally being assessed as separate entities, the close relationship between intelligence and curiosity in infancy underscores the need to understand these variables together.

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LIST OF ACRONYMS

AP	Academic Performance
APM–SF	Advanced Progressive Matrices—Short Form
AT	Abstract Thinking (factor)
CAB–I	Cognitive Assessment Battery—Inductive Reasoning
CFD	Curiosity as a Feeling of Deprivation (= D–type curiosity)
CFI	Curiosity as a Feeling of Interest
CHC	Cattell-Horn-Carroll (theory of intelligence)
D	Deprivation (factor of IC)
D–type	Curiosity as a Feeling of Deprivation
EC	Epistemic Curiosity
EC–D	Epistemic Curiosity—Deprivation (= D–type curiosity)
EC–I	Epistemic Curiosity—Interest (= I–type curiosity)
EC/D	Epistemic Curiosity—Diverse Interest
EC/S	Epistemic Curiosity—Specific Interest
FFM	Five Factor Model of personality
g	general intelligence
Gc	Crystallised Intelligence
Gc (psych)	Crystallised Intelligence (psychology)
GMA	General Mental Ability
GPA	Grade Point Average
Gv	General visual perception
IA	Intellectual Avoidance (factor of IC)

IAT	Implicit Association Test
IC	Intellectual Curiosity
IPIP	International Personality Item Pool
IPIP–Intellect	International Personality Item Pool—Intellect scale
I–D	Interest–Deprivation model of curiosity
I–type	Curiosity as a Feeling of Interest
LMG	Lindeman Merenda Gold method
MH	Mill Hill vocabulary scale
NEO-FFI	NEO Five-Factor Inventory
NEO-PI-R	Revised NEO Personality Inventory
NFC	Need for Cognition
O	Openness/Intellect domain
OCEANIC	Openness Conscientiousness Extraversion Agreeableness Neuroticism Index Condensed
OE	Openness to Experience
OFCI	Openness–Fluid–Crystallized–Intelligence model
OI	Openness to Ideas
OR	Orienting Reflex
PC	Perceptual Curiosity
PC/D	Perceptual Curiosity—Diversive
PC/S	Perceptual Curiosity—Specific
PPIK	Intelligence–as–Process –Personality –Interests and –Knowledge
PS	Problem Solving (factor of IC)
R	Reading (factor of IC)

RMSEA	Root Mean Square Error of Approximation
SC	Sensory Curiosity
SES	Socioeconomic Status
STW	Spot-the-Word test
TIE	Typical Intellectual Engagement
TOEFL	Test of English as a Foreign Language
TOT	Tip of the Tongue phenomenon
Type A	Fluid intelligence (Hebb)
Type B	Crystallised intelligence (Hebb)
VPR	Verbal, Perceptual, image Rotation model of intelligence
WI	Wide interest (factor of IC)

DECLARATION

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DEDICATION

This thesis is dedicated to my father, Michael

Preface

Two earlier papers provide some background to the series of studies conducted as part of this dissertation. The first paper (Powell & Nettelbeck, 2014a) reported an honours project assessing the issue of incremental validity for intellectual curiosity (IC) in predicting academic performance (AP) above cognitive ability and Conscientiousness. It reported only limited evidence of incremental validity for one measure of IC—and none for three others—and concluded that IC may not incrementally predict AP. In part, this project was inspired by the meta-analysis of von Stumm, Hell, et al. (2011), which proposed that intellectual curiosity is the "third pillar" of AP. This initial study was not conducted as part of this dissertation, and therefore has not been included.

The second background paper (Powell & Nettelbeck, 2014b) was a surrejoinder to a critique of the first that was published by von Stumm, Hell, and Chamorro-Premuzic (2014), who claimed that several 'issues' they found in Powell and Nettelbeck (2014a) called into question its broad findings. The surrejoinder acknowledged several of the stated issues, but maintained that they did not affect the original study's main conclusion, namely that the von Stumm et al. (2011) proposal was questionable. Because the surrejoinder was published within the period of candidature, it could have been incorporated formally within the dissertation. This was not done, however, because, although the comments were consistent with subsequent conclusions drawn in this thesis, they are largely redundant given the research that has followed.

1 INVESTMENT THEORY

1.1 Introduction

Cattell's "investment theory" of intelligence was developed as part of intelligence theory more broadly, and can be best understood within this context. The overall aim of this chapter is to provide an overview of investment theory, and assess whether this remains a viable framework for intelligence and personality research in the present day. This chapter is presented under five main headings: *The Discovery of General Intelligence*, *The Discovery of Fluid and Crystallised Abilities*, *Cattell's Investment Theory*, *Ackerman's PPIK Theory*, and *Assessment of Investment Theory*.

1.2 The Discovery of General Intelligence

This history of the discovery of general intelligence has been recounted many times before, and need not detain us long. A brief overview of the contributions of Galton, Spearman, and Binet will provide the background against which Cattell proposed his conceptions of Gf, Gc, and investment theory.

Galton

Francis Galton (1822—1911) is a superb candidate with whom to begin a study about intellectual curiosity. A man of insatiable curiosity, his contributions to science spanned diverse areas including geography, anthropology, genetics, psychology, statistics, and personality.[1] In these last two areas alone, he discovered independently the correlation, regression toward the mean, and the lexical hypothesis of personality. Arthur R Jensen (2002) concluded that Galton's contribution on the topic of general

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[1] To say nothing of his contributions to domestic life, including how properly to brew tea (Galton, 1855) and how to cut a cake in order to leave the least amount of surface area exposed (Galton, 1907).

mental ability (GMA) was seminal, and directed subsequent research in terms of its existence, heritability, measurement, and racial differences.

Galton believed that GMA was a broad trait, and highly heritable. His book *Hereditary Genius* (1869) was an extended argument that intellectual ability is heritable, which Galton substantiated by surveying numerous eminent figures and arguing that this eminence (which he used as a proxy for intelligence) was attributable to the individuals' family histories.[2] Its third chapter "Classification of Men According to their Natural Gifts" argued that because human beings are not born with equal physical abilities and physical dimensions, they should not be expected to possess equal GMA—evidenced from the distribution of scores for mathematical honours students at Cambridge. To quote Galton at length:

> In statesmanship, generalship, literature, science, poetry, art, just the same enormous differences are found between man and man; and numerous instances recorded in this book, will show in how small degree, eminence, either in these or any other class of intellectual powers, can be considered as due to purely special powers. They are rather to be considered in those instances as the result of concentrated efforts, made by men who are widely gifted. People lay too much stress on apparent specialities, thinking over-rashly that, because a man is devoted to some particular pursuit, he could not possibly have succeeded in anything else. They might just as well say that, because a youth had fallen desperately in love with a brunette, he could not possibly have fallen in love with a blonde. He may or may not have more natural liking for

[2] Galton's lineage is consistent with this perspective: he was Charles Darwin's half-cousin.

> the former type of beauty than the latter, but it is more probable as not the affair was mainly or wholly due to a general amorousness of disposition. (Galton, 1869, p. 64)

Thus, for Galton the abilities of eminent individuals were the consequence of GMA applied to specific domains, rather than being more specialised abilities. However, he did not neglect environmental factors, seeing them as providing the specific opportunities for GMA to be applied. But nurture could only work with what nature provided.

Often, Galton was not able to substantiate fully many of his intuitions, due to limitations in the statistical and research methods of his day. Although he used the proxies for GMA available to him, such as mathematics scores and perceived eminence, he was not only a product of his time but was also constrained by it. Nonetheless, Galton was a towering figure, and over the following century many researchers have continued the journey from where he left off.

Spearman

Like those of Galton, the contributions of Charles Spearman (1863—1945) to statistics and psychology are manifold. Spearman came to psychology relatively late in life: after many years of military service, at age 34 he began a PhD in experimental psychology under Wundt, completed in 1906. During his doctoral studies he published a pair of influential papers on rank-order correlation and correction for measurement error (Spearman, 1904b) and intelligence (1904a), which were both highly influential.

Spearman's account of intelligence (1904a) is the most important for our purposes, for this was the first demonstration of a general factor of cognitive ability—the factor that Galton inferred but could not demonstrate empirically. Spearman's participants were students from a village school, an Oxford preparatory school, and adults from the community, and his assessments included the students' sensory discrimination, academic performance (in Classics, French, English, and Maths), and other-rated intelligence.

Spearman (1904a) reported that individual measures of sensory discrimination correlated substantially with individual measures of intelligence, and that variance common to measures of sensory discrimination (which he called "General Discrimination") correlated strongly with variance common to measures of intelligence ("General Intelligence"). Moreover, when corrected for measurement error, these correlations were exceptionally close to 1—indicating that what was common among measures of sensory discrimination was common to measures of intelligence. Based on this and other evidence, Spearman concluded:

> On the whole, then, we reach the profoundly important conclusion that *there really exists a something that we may provisionally term " General Sensory Discrimination " and similarly a " General Intelligence," and further that the functional correspondence between these two is not appreciably less than absolute.* (1904a, p. 272, italics in original)

This evidence for general intelligence (*g*), coupled with Spearman's argument for specific factors (*s*) that explained variance in tests not explained by the general factor, formed his two-factor theory of intelligence (elaborated in Spearman, 1928), an account with which future researchers would dialogue. Further, alongside Galton, Spearman argued that intelligence was strongly heritable. Although his immediate counterpart Binet would disagree with many of his positions (though not entirely), they would make a resurgence later in the twentieth century, especially in the work of Jensen (1998).

Binet

For a man with no formal training in psychology, Alfred Binet's (1857—1911) impact on this field has been remarkably enduring. Being independently wealthy, he could pursue research out of pure interest, and he digested the works of Darwin, Galton, and especially John Stuart Mill. Binet initially studied law and received his license, but apparently never practiced (Siegler, 1992). His first research career involved testing the effects of magnets on human behavior, with positive results. However, other researchers had failed to replicate his findings, eventually leading him to acknowledge that his subjects knew the purpose of the experiments, leading him to abandon this avenue of enquiry (Siegler, 1992).

Binet's second career involved assessing intellectual deficiency in children, and was far more successful. Rather than assessing intellectual ability indirectly through measures of sensory function or academic performance (in the tradition of Galton and Spearman), Binet sought to measure ability directly through tests designed for this purpose. He argued that cognitive function involved various individual processes and therefore measuring intelligence required sampling these processes adequately to allow calculation of a composite score that reflected a person's overall ability (Siegler, 1992). Moreover, while Galton and Spearman emphasised the "nature" side of the origin of intelligence, Binet emphasised the "nurture" side, believing that all people could take steps to improve their intellectual function.

Binet's lasting contribution involved not only his conception of intelligence, but the tests themselves, which were referenced against age-specific norming samples, making this approach conceptually different from measuring objects with physical dimensions, as its authors observed (Binet & Simon, 1905). Although initially Binet and Simon's tests were largely ignored in their native France, they impacted greatly intelligence testing in the US. Their scales underwent numerous revisions and translations during Binet's and Simon's lifetimes, and their broad approach proved remarkably successful long after their passing (Siegler, 1992).

1.3 The Discovery of Fluid and Crystallised Abilities

Introduction

Raymond B. Cattell (1905—1998) was a brilliant intelligence and personality theorist, and a student of Spearman. At the time when Cattell (1943) proposed his theory of fluid and crystallised intelligence, he lamented the lack of recent conceptual progress for intelligence theory. Although many intelligence tests were available, the underlying theory had barely developed in the recent decades, making the proliferation of tests meaningless: "A simile adequate to illuminate the present incredible state of affairs in intelligence theory is not easy to find. It is as if one came prepared to view a museum of prehistoric animals and awoke to a nightmare realization that the monsters were alive and loose" (1943, p. 158).

Cattell was especially concerned that intelligence tests should not float free of theoretical moorings: test validation was being spoken of apart from intelligence theory, with validation only in the form of correlation with previous tests. This circularity assumed a basis in intelligence theory for which Cattell could not find sufficient evidence. Especially, Cattell lamented the various contradictory definitions of intelligence:

> Intelligence is abstract thinking ; it is concrete thinking ; it is verbal skill ; it is manipulative ability ; it is innate ; it is a set of acquired skills ; it occurs equally in all activities ; it cannot be measured by sampling ; it is one thing ; it is a host of things ; it is a few distinct, clear-cut aptitudes. (1943, p. 163)

Cattell therefore sought to define intelligence in such a way that allowed it to emerge from the morass of thinking at the time; was it one thing (Spearman) or many things (Thurston)? When faced with two facts in apparent tension, it is sometimes wise to suspend judgment, allowing time for a synthesis to appear. Or in Spearman's words, "one fact cannot destroy another, and any apparent conflict merely proves our imperfect acquaintance with their true nature" (1904a, p. 271). Although both Spearman and Thurston held to their distinctive positions, Cattell discerned that they left room for each other—that they shared a "common destiny" (Cattell, 1943, p. 169). But the missing element, as Cattell would demonstrate, was a middle tier in the hierarchy, between primary abilities and the general factor.

The Evidence

Given Cattell's admiration for Spearman, it was with some unease that he proposed that Spearman's general ability factor was at least two factors. This suggestion was based on evidence that was apparently anomalous from the perspective of those advocating a sufficient explanation in terms of a general ability factor. Cattell (1987) later summarized those six indications that *g* was more differentiated than first thought:

(1) Research into perceptual (i.e. non-verbal) measures of intelligence, including from Spearman's laboratory, found that these were correlating more

substantially with each other than with more verbal and scholastic measures of intelligence, which formed their own group.

(2) Perceptual and verbal tests showed distinct pre-adult developmental trajectories, with the growth curve of perceptual abilities flattening out earlier (around 13 years) than the same for verbal abilities (around 17 years).

(3) The second-order analysis of Thurstone (1938) suggested more than one general factor. With more adequate methods of determining the number of factors to extract, it became clear that a single factor was not sufficient within the higher-order analysis.

(4) The standard deviations for perceptual versus verbal tests were significantly different, being around 24 points for the perceptual tests—once these had been segregated—compared with the traditional figure of about 15-16 for the undifferentiated construct.

(5) Acquired brain injuries appeared to have distinct effects on identifiable aspects of intelligence. For instance, injury to specific brain areas might affect verbal ability but leave numerical ability unaffected, while any kind of brain injury seemed to result in some decrement to overall perceptual ability.

(6) The declines in abilities throughout adulthood followed distinct paths, with perceptual abilities declining steadily from about 20-25 years, while verbal abilities appeared to plateau over the next 40 years, declining thereafter.

Cattell argued that these observations could not be squared with the notion that a single, general construct defines adequately the results from of the subtests of intelligence. From his perspective, intelligence theorists were “trying to run before they have learned to walk" (Cattell, 1943, p. 162). He sought an explanation that would weave these strands of evidence into a coherent pattern.

The Synthesis

However, Cattell was not the only person who noticed these discrepancies; others had been wrestling with the same issues, though sometimes in different domains of expertise. Donald Hebb (1904—1985) had been researching the impact of brain injury on intelligence test scores and had noted that injuries sustained for infants had difference consequences than those sustained by adults—as noted in point 5 above. If a brain were injured before it had developed to maturity, this resulted in a more symmetrical reduction of abilities. However, if a mature brain were injured, this often resulted in an asymmetry of abilities, where verbal abilities might be retained but problem-solving abilities were impaired (Hebb, 1942). As noted earlier, Spearman's *g* would not predict this difference but, instead, a more consistent effect regardless of age.

From this limited evidence, Hebb (1942) proposed two types of intelligence, labeled *A* and *B* respectively, in the following hypothesis:

> *In any test performance there are two factors involved, the relative importance of which varies with the test: one factor being present intellectual power, of the kind essential to normal intellectual development; the other being the lasting changes of perceptual organization and behavior induced by the first factor during the period of development.* (p. 287, italics in original)

Hebb first proposed this distinction at the APA Annual Meeting in 1941, where Cattell also presented his interpretation of the evidence. Cattell (1943) regarded Hebb's proposal as "two thirds" (p. 179) of his own theory. He retained the essential distinction between Hebb's type A and B abilities, but preferred the terms "fluid" and "crystallised" intelligence to convey their nature.

Defining a general factor of fluid intelligence (Gf) is relatively straightforward. In Cattell's words, it "has the 'fluid' quality of being directable to almost any problem" (1987, p. 97). The rapid increase in fluid ability over the developmental years is a function of the brain as it matures, which explains why this increase levels out once maturity is reached. Fluid intelligence is a flexible, ubiquitous, effortful, and general capacity to perceive relationships, and its strength will be a significant factor in the success of any intellectual endeavor. This seems to be the essence of Spearman's definition of general ability as the educing of "relations" and "correlates" (1928, pp. 165-6). Cattell (1943) understood fluid intelligence to be relatively stable, and free of cultural constraints when measured appropriately. He also saw it as heritable, but noted that this should not be taken to imply "anything like complete hereditary determination", because the quality of the environment during the gestation period and brain injuries sustained after birth could affect subsequent development (Cattell, 1963, p. 4).

Cattell labeled crystallised intelligence (Gc) thus because it is "a freezing in a specific shape of what was once a fluid ability" (1987, p. 140). As crystallised ability represents the brain's stored knowledge, this capacity can continue to grow after the developmental period has ended—thus its different growth curve from Gf. It relates to acquired skills, and is thus domain-specific, involves relatively less effort to employ than Gf, and is influenced substantially by culture. Defined more extensively: "crystallized ability (g_c) expressions, though of a judgmental, discriminatory, and reasoning nature, operate in areas where the judgments have been taught systematically or experienced before" (1987, p. 115). Thus, essentially, these two types of general intelligence perform similar functions, but which one is used depends on whether the learning task has been encountered previously.

However, despite the above definition, a closer look at Gc suggests that it is relatively more difficult to capture and fully understand than Gf—an issue that remains to this day (Keith & Reynolds, 2010). Cattell called it "Protean"[3] because of its changeable nature. As he observed, "Cultural change, shift of mixture of areas intellectually fashionable, or a change in the school curriculum can weaken its identity and unity as a discernible factor, even in the teenage school period when it is most prominent" (1987, p. 149). Thus, being at the mercy of whim, culture, and curriculum, crystallised intelligence can take various forms. This definition of Gc will be expanded shortly, but this must wait until two other issues have been unpacked: Cattell's interpretation of Spearman's *g*, and Cattell's proposed "investment theory" to explain the relationship between Gf and Gc.

This bifurcation of *g* into Gf and Gc raises the question of whether Spearman's *g* retains a place in Cattell's framework. Cattell (1963) argued that *g* could be interpreted meaningfully, and that it represented the fluid ability of yesteryear—that is, the historical fluid intelligence that was operating at the time when the crystallised ability currently being measured was formed. Through the process of maturation, historical Gf "fathers" current Gf out of time, and is "invested" in Gc (Cattell, 1963, p. 15). He illustrated this concept of a factor which represents historical influence with the illustration of a group of adults, some who had not skied since turning 15 years old,

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[3] Proteus was the Greek god of rivers and oceans, who is said to be constantly changing, as is the nature of bodies of water.

and others who had never skied (1987, p. 142). He suggested that we should expect to find a correlation between current skiing ability and prior experience—weak but significant—which would represent the residual effect of skiing experience in the developmental period. In the same manner, Spearman's *g* would reflect the "investment" of Gf into Gc during the developmental period, which produced the type of Gc at hand.

1.4 Cattell's Investment Theory

Having introduced Cattell's language of "investment", we can now explain his "investment theory". Although Cattell's account was the most extensive at the time, others had provided briefer accounts which expressed a similar idea. As noted earlier, Galton had argued that eminent individuals were not necessarily specially gifted by nature for those domains in which they excelled, but that their abilities were "the result of concentrated efforts, made by men who are widely gifted" (Galton, 1869, p. 64). Spearman proposed a hypothesis of "energies", "engines", and (more tentatively) an "engineer". He suggested that the brain contained a general mental energy, which was supplied to engines, which he thought were different neural systems (1928, p. 133). This process was directed by the engineer, which he suggested was the *w* factor identified by Webb (1915)—now seen to approximate Conscientiousness within the Five Factor Model (FFM; Costa & McCrae, 1992a). And Hebb, whose contribution we have already noted, theorised that "Intellectual development then would involve stable, qualitative changes of behavior and perception, dependent for their first appearance upon more elaborate intellectual processes than for their later functioning" (1942, p. 286). All these suggestions resemble the account provided by Cattell, whose theory owed a large debt to his predecessors.

However, Cattell developed his ideas far beyond any of these suggestions, by clarifying the nature of these general factors, and providing an account of their relationship and development. He labeled this "investment theory", drawing upon financial imagery: "because crystallized ability becomes the trustee of gains from investment by fluid ability" (Cattell, 1987, p. 120). As Cattell noted, investment theory also incorporated evidence from developmental and social research to explain the manner of this investment (1987, p. 138). Thus, its wide-ranging nature made it complex and speculative at points—perhaps necessarily, given the complexity of human beings.

Cattell believed that Gc was substantially influenced by two aspects of culture: the school system earlier in life, and occupational differences later in life. As Cattell noted in his earlier statement on the subject, "Intelligence tests test at all ages the combined resultants of fluid and crystallized ability, but in childhood the first is predominant whereas in adult life, owing to the recession of fluid ability, the peaks of performance are determined more by the crystallized abilities" (1943, p. 178). For the development of Gc from Gf in adolescent populations, investment theory held a unique role for the school curriculum. In modern times, most adolescents within developed countries are exposed to a common curriculum including maths, the country's native language, and science. Therefore, despite the students' natural inclinations, school curricula direct their mental energies to "invest" predominantly in those pre-determined subject domains. Cattell held this curriculum in the widest sense to be largely responsible for the general factor of crystallised knowledge. When speaking of the pattern for several distinct school subjects to exist as defining the Gc factor, he argued:

> Empirically, we have to recognize that this unitary pattern, long the target of traditional intelligence tests, expresses itself in the school years and for some time afterwards as a set of high correlations among numerical ability, grammatical sense, size of vocabulary, and other relationally complex and abstract skills trained in the typical school curriculum. (Cattell, 1987, p. 142)

In this way, the presence of a common curriculum was crucial for the development of the Gc factor. Without this, we would not expect to find it at all—at least when measured by school-based knowledge. Therefore, in a teenage population *g*, Gf, and Gc should all correlate strongly, because the rapidly-developing Gf will quickly overtake more domain-specific abilities, making a large discrepancy between these areas difficult to sustain for long (Cattell, 1987, p. 151). Gc is thus prevented from developing far ahead of the Gf due to the latter's rapid development.

Once maturity is reached, however, this situation would change. Adults have left the common school curriculum behind, and so the natural decay of knowledge from the school years, coupled with the diversification of interests and occupations, would lead to a situation where the ongoing development Gc factor would look quite different in adults:

> As to the latter we must note that after school, as investments of intelligence in different occupational and other skills are added to scholastic skills (e.g., skills in selling, in engineering, in driving buses, in making pies, and in managing small children) the older pattern common to all people who attend school should begin to disperse – or, at least, abrade – and give way to the rise of new kingdoms. Empirically, this means that the correlations constituting the earlier

> crystallized ability pattern should begin to be less dependable (Cattell, 1987, p. 142).

Thus, the strength of the relationships between Gf, Gc, and *g* might be substantially less than they were during the childhood developmental period. "Indeed, beyond the school years the correlation of present g_f and present g_c may become relatively poor" (Cattell, 1987, p. 152). As Cattell noted, we might expect as many crystallised "intelligences" as there are occupations (1987, p. 143).

This raises another important consideration, that to speak of a "general" crystallised factor may be too simple. Cattell argued for at least four distinct Gc factors, the presence of which will differ according to the cohort being investigated. Given two-fold distinctions between both the third-order *g* and the second-order crystallized intelligence factor, and between childhood and adulthood crystallised ability, Gc could be decomposed into four distinct concepts: (1) school age crystallized intelligence, (2) school age crystallized achievement, (2) adult activity crystallized intelligence, and (4) adult activity crystallized achievement. This obviously makes for a complicated equation and, given the strong relationship between these four aspects, they may only be distinguishable theoretically—or through a "comprehensive organization of experiments" (Cattell, 1963, p. 10).

The difference between school-age and adult factors is the presence of the school curriculum, but the difference between crystallised "intelligence" and crystallised "achievement" requires more nuance. We might distinguish here between "narrow" Gc and "broad" Gc. Narrow Gc relates to Cattell's preferred understanding of Gc: specific knowledge which is the consequence of applying insightful perception to a difficult intellectual task. This is to be distinguished from broad Gc, which can be produced by relying less on applied, insightful perception, and more on rote memory and exposure. For instance, Cattell understood school age crystallised achievement to be a broader concept which spanned “intelligence, memory, special ability areas, etc., corresponding purely to the effect of common time, interest, memory, and curriculum” (1963, p. 9). In a significant way, the narrow investment of Gf into Gc was the core of investment theory, while the broad’ products of Gc (in childhood and adulthood) were the Protean, incidental consequences of this process. We can speak of a broad Gc factor in adolescence only because of the historical accident of schooling, but history might have been otherwise.

Thus, Gc proper is not reducible simply to verbal ability, because a large vocabulary might be obtained by somebody with poor Gf but an excellent memory. We will not critique Cattell’s fine-grained distinctions here, but simply note that Cattell’s definition of Gc proper was fairly narrow, and thus excluded concepts such as school achievement, with which initially it may be thought to be identical. Cattell’s four distinctions within Gc did identify school achievement as a form of Gc, but distinguished this from investment in his narrow sense—a distinction that subsequent research has not always been careful to follow.

Moreover, although investment theory may look like a one-way street, where investment takes place uniformly from Gf to Gc, Cattell noted that the reality would be more complicated than this, and that these factors might exist in a relationship of reciprocal determinism. In labeling these factors, alternative labels for Gf and Gc were “process” and “product” respectively, which had been used by other researchers, including Newland (1962). However, despite their intuitive appeal, Cattell objected to these labels, except as loose descriptions. He argued that the capacity to learn is not simply a function of the process, but may also be influenced by the product: prior learning (Cattell, 1963). Thus, Gc may not only be the product of invested fluid ability, but may also be a product of earlier instances of itself. Essentially, the idea was that learning begets learning—adding complexity to an otherwise more straightforward equation.

In addition, Cattell suggested that levels of interest would play a role in the investment process—especially because this interest is predicted by personality variables that influence engagement with the school curriculum. Speaking of the positive correlations found between different subjects within the school curriculum—the basis of the Gc factor—Cattell noted that “they arise also from dynamic causes, in the form of some children being more strongly interested in all that may be called intellectual matters and school achievement” (1987, p. 143). This personality characteristic might be labeled “intellectual curiosity” (IC), and has a place not only as a predictor of academic achievement, but also in the development of Gc. Personality traits held to play a part in the development of Gc have been called “investment traits” (von Stumm, Hell, et al., 2011). Although Cattell noted them, their role in the process of investment has been more fully developed in Ackerman’s account of intelligence (1996).

Predictions of Investment Theory

Cattell provided a remarkable synthesis of the evidence available to him, not only by distinguishing between Gf and Gc, but by providing a lucid account of their mutual development and influence. In the years since Cattell’s comprehensive statement of investment theory (1987), various studies have been conducted that bear weight on his theory. Although more predictions could be elaborated, we shall survey four here: (1) correlations between Gf and Gc, (2) homogeneity and the relationship between *g* and Gf, (3) heritabilities of Gf and Gc, and (4) the developmental influence of Gf on Gc.

(1) Correlations between Gf and Gc. An important prediction of Cattell's theory was that Gf and Gc should correlate strongly in the developmental years, due to the common content of the education system. However, once this rapid developmental period was over, and the students had left school and had more opportunity to pursue selective interest (either through tertiary or other vocational training), this relationship would be expected to diminish, because the common school curriculum no longer binds Gf and Gc together. Gf and Gc would remain in a strong relationship until the end of compulsory education, but less so thereafter.

(2) Homogeneity and the relationship between *g* and Gf. Investment theory predicts that the relative loading of *g* on Gf and Gc will be a function of cultural similarity, especially educational opportunity. As noted before, Cattell saw Gf as a ubiquitous entity, involved in all manner of mental operations. Therefore, the Gf of those students who have experienced very similar upbringings and educations (i.e. homogeneous populations) should load very strongly on a higher-order *g* factor. Their mental effort has largely been applied within a set framework, and thus differences should be attributed largely to differences in ability. Nevertheless, Cattell himself expected this relationship to fall short of parity: "However, the g_f factor will not account for *all* of the correlation in this case, as it does in the non-cultural, overlearned, or new problem-solving, because years at school, interest in school work, and other influences will also determine, perhaps substantially, the level of crystallized abilities” (1987, p. 139). Conversely, the Gf of those with less similar backgrounds (i.e. heterogeneous populations) should be lower.

Thus, Cattell’s investment theory predicts that Gf should possess the most stable meaning of these three factors. The meaning of Gc in any assessment is in part determined by culture, the school curriculum, experiences over time, and differences in occupational knowledge. Spearman’s *g* is variable, too, and the strength of its relationship with Gf depends on the degree to which a test sample has a uniform upbringing of culture and education.

(3) Heritabilities of Gf and Gc. Investment theory also predicts that the heritabilities of Gf and Gc would differ significantly. As Gf is interpreted as an innate, biological reasoning capacity, its heritability should be higher than that of Gc, which is more culturally determined. In samples where experiences of participants were highly homogeneous, heritabilities for measures of Gc might approach those of Gf, but would not be expected to exceed them. Cattell (1987) acknowledged the limitations of the data available to him, but argued that the broad trend of these data supported—though not unequivocally—his perspective on the relative heritability of Gf and Gc.

(4) Developmental influence of Gf on Gc. Finally, investment theory predicts that Gf should exert a stronger developmental (i.e. longitudinal) influence on Gc than Gc does on Gf. Given that Gf is conceptually and developmentally prior to Gc, we should expect that longitudinal studies in which these variables had been measured at different points in time, and with sufficient statistical power, would show this pattern. Although Cattell also allowed that the development could also flow from Gc to Gf, this should not be as strong as the influence from Gf to Gc because of the primacy of Gf in this theoretical account.

Summary

Cattell's theory of the investment of Gf into Gc clearly related more strongly to children more than to adults, and predicted that this investment would change significantly in the years following mandatory education. Although Cattell provided several intuitions about what investment might look like in adult populations, his statements regarding this group were less detailed and more speculative. For Cattell, investment in childhood and adult cohorts were qualitatively different, but beyond some speculations about personality variables that might be important in the development of adult intelligence, he left some pieces of a puzzle for others to complete.

1.5 Ackerman's PPIK Theory

Introduction

Phillip Ackerman has provided a comprehensive, integrative account of adult intelligence in the spirit of Cattell. His PPIK (intelligence–as–process, –personality, –interests and –knowledge) theory of adult intelligence (1996) was also an investment theory, and an extension of Cattell's model. It provided an extended account of the development of intelligence in adults, with special concern for the different structures that determine knowledge acquisition in adults. As Cattell noted, the nature of the investment of Gf into Gc would change dramatically once compulsory education had ended, and PPIK incorporated this insight. In this section, we will survey: (1) the historical background, (2) the components of PPIK theory, and (3) its relationship with Cattell's investment theory.

Historical Background

According to Ackerman (1996), the early contribution of Binet and Simon strongly influenced the subsequent approach to intelligence research. Binet and Simon (1905) identified three potential approaches to testing intelligence: (1) the medical method, which looked for physiological explanations for differences in intelligence, (2) the pedagogical method, which assessed intelligence as the sum of acquired knowledge, and (3) the psychological method, which assessed intelligence directly through sampling reasoning ability. Binet and Simon (1905) identified the psychological method as having the most promise, and their pursuit of this method, noted Ackerman (1996), set the course for the subsequent research across much of the 20th century.

Ackerman (1996) accepted that the psychological method had been very successful in children: "There is, indeed, no essential difficulty with this approach for the testing of children and adolescents for the school performance criterion" (Ackerman, 1996, p. 228), because school performance is the appropriate outcome variable in childhood and adolescence. However, Ackerman (1996) questioned "whether upward extensions of the Binet-Simon scales are optimal for describing adult intellect, or the development of intellect in adults" (p. 228).

Specifically, Ackerman (1996) argued that applying to adults the same construct of intelligence that had been developed for children was inappropriate for three reasons: (1) the concept of an intelligence quotient—a child's mental age divided by her chronological age—makes little sense for adults, because many aspects of intellectual development usually plateau before the age of twenty; (2) many adults with apparently lower intelligence nonetheless develop expertise in their professions and hobbies, suggesting that acquired, relevant knowledge may become increasingly important for adults—a concept not thoroughly assessed in many intelligence tests; and (3) applying such intelligence tests in adult populations predicted only a portion of the variables in adult achievement, such as academic or work outcomes, suggesting that variables such as personality traits may become more salient predictors in adulthood. Thus, given the differences between adolescent and adult populations, Ackerman argued that assessing intelligence in adults warranted a fresh conception, which he introduced in PPIK.

The Components of PPIK Theory

Process. We shall survey the components of PPIK in order, starting with intelligence-as-process. Ackerman retained the notion of a general abstract problem solving ability (Cattell's Gf) but preferred to designate it as "Process". Process included Gf but was broader, involving a number of aspects crucial for information processing, such as working memory, processing speed, and spatial rotation—abilities which seemed to develop together during adolescence, suggesting their close mutual relationship (Ackerman, 1996). However, having proposed the continued significance of Process intelligence for adults, he noted that it may not be as powerful a predictor of intellectual development as it was in adolescence. Thus, Ackerman highlighted the inherent difficulty in separating process intelligence from knowledge, because in adults existing knowledge structures may be the best predictors of future development (1996). It is noteworthy that this objection is the same that Cattell made of Newland's (1962) use of "process" and "product", where the prior amounts of a product may determine its future acquisition. However, for description and analysis, Ackerman preferred the label Process to Gf.

Personality. The second component of PPIK is intelligence-as-personality. Ackerman's (1996) move to formally incorporate personality variables into the framework of intelligence marked a significant shift in perspective for intelligence theory. When introducing Typical Intellectual Engagement (TIE), Goff and Ackerman (1992) suggested that the history of intelligence theorising had been characterised by measuring "intelligence as maximal performance"—the traditional domain of intelligence tests. However, they argued that the lack of predictive power when using this approach in circumstances such as late-stage skill acquisition implied that something was missing in this conception, which they argued was "intelligence as typical performance". Thus, the development of the TIE scale was intended to measure this tendency, and to define clearly a personality variable understood to be relevant to acquiring knowledge.

Ackerman (1996) noted two particular personality variables that captured intelligence-as-personality: Openness within the Five Factor Model (FFM; Costa & McCrae, 1992a), and Typical Intellectual Engagement (Goff & Ackerman, 1992). In this earlier study (Goff & Ackerman, 1992), these two factors appeared to show little overlap with intelligence-as-process, with negligible correlations between Gf and TIE ($r = -.06$, $p > .05$) and between Gf and Openness ($r = -.02$, $p > .05$) indicating their independence. Goff and Ackerman (1992) also reported correlations between Gc and Openness ($r = .22$, $p < .05$), and between Gc and TIE ($r = .22$, $p < .05$), indicating significant overlap with intelligence-as-knowledge. In addition, the meta-analysis of Ackerman and Heggestad (1997) reported substantial correlations for both TIE and Openness with Gc ($\rho = .35$ and .30 respectively, both $p < .05$), and with a measure of knowledge and achievement ($\rho = .23$ and .28 respectively, both $p < .05$)—far more substantial than for the other FFM variables surveyed. Thus, the correlations between both Openness and TIE and the relevant factors of intelligence were consistent with the predictions of PPIK theory.

This raises the question of the relationship between Openness and TIE. Goff and Ackerman (1992) reported a strong correlation between Openness and TIE ($r = .65$, $p < .05$). This overlap, considered alongside the very similar correlations between both TIE and Openness with Gf and Gc indicated to Rocklin (1994) that these factors were addressing the same underlying construct, and that the correlation was less than perfect only because of measurement error. However, Ackerman and Goff (1994) rejected Rocklin's arguments, citing TIE's differential relationship with the six facets of Openness to Experience as evidence of its theoretical distinctness—TIE related most closely with the facet Openness to Ideas ($r = .77$, $p < .05$), but least closely with Openness to Fantasy ($r = .26$, $p < .05$). Thus, they argued that Openness and TIE were distinct constructs, despite being related.

Having confirmed the relationship of Openness and TIE with broad Gc, Ackerman and colleagues then related them to more specific knowledge measures. In the first study, Rolfhus and Ackerman (1996) compared FFM domains and TIE with self-reported knowledge across 20 domains including music, literature, biology, architecture, algebra, and statistics. They obtained salient correlations ($r > .3$) between both TIE and Openness and several knowledge domains, particularly those from the art, and humanities and social science clusters. No other FFM factors correlated saliently with any self-reported knowledge domain, indicating that TIE and Openness might relate more strongly to some knowledge domains than others. The remaining four FFM factors did not show substantial correlations with these domains, indicating that they were not part of the investment process.

However, a substantial weakness of this study was its reliance on self-reported knowledge rather than assessed knowledge. This weakness was addressed by Rolfhus and Ackerman (1999), who developed scales to measure the 20 knowledge domains used in the earlier study. They predicted that Openness and TIE would relate more strongly with knowledge of humanities than science domains, while the other FFM variables would not relate substantially to intelligence-as-knowledge. These predictions were broadly confirmed, although Extraversion had significant, negative relationships with nearly all domains. TIE and Openness broadly predicted knowledge across domains, but the trend was a more substantial overlap with humanities and arts subjects than with science and mechanical domains. The broad pattern of relationships therefore matched predictions based on PPIK.

Interests. The third component of PPIK is intelligence-as-interests. To assess interests, Ackerman (1996) used Holland's (1959, 1973) framework, which identified six types of occupational interest: Realistic, Investigative, Artistic, Social, Enterprising, and Conventional (Holland, 1996). The meta-analysis of Ackerman and Heggestad (1997) assessed these six interest types, and found that only the first three overlapped substantially with intelligence. Defined briefly: realistic (originally "motoric") interests express themselves in occupations that involve physical strength and motor skills, such as labouring, mechanical trades, and engineering; investigative (originally 'intellectual') interests express themselves through occupations involving the pursuit of knowledge and understanding; and artistic (originally "esthetic") interests express themselves through artistic pursuits such as painting, writing, and music (Holland, 1959).

Comparing these three interest domains with intelligence, Ackerman and Heggestad (1997) reported that realistic interests correlated predominantly with spatial, mathematical and mechanical (i.e. process) abilities, investigative interests correlated with spatial, mathematical, and verbal (process and knowledge) abilities, and artistic interests correlated mainly with verbal (knowledge) ability. This differential pattern of relationships depending on interest type is predicted by PPIK, which suggests that interests and relevant abilities will overlap significantly because they are both involved in the developmental process.

Not only do interests relate to the broad abilities, but they also relate to the narrower domains of knowledge. The study of Rolfhus and Ackerman (1996) compared Holland's interest types with self-reported knowledge scales across the same 20 narrow domains and found that knowledge in the mathematics and physical sciences cluster correlated saliently with realistic and investigative interests; knowledge in the technology cluster was predicted by realistic interests; knowledge in the bio-social science cluster was predicted by investigative interests; and knowledge in both the art and humanities and social sciences clusters were predicted by artistic interests. These correspondences between knowledge and their corresponding interest type are consistent with the predictions of PPIK theory.

In their follow-up study which used assessed knowledge scales, Rolfhus and Ackerman (1999) also compared interest types with assessed knowledge domains. They reported that realistic interests predicted knowledge within science and mechanical knowledge clusters, as did investigative interest, while artistic interests predicted knowledge in the humanities, civics, and some domains of science. Concerning the relationship between interest types and knowledge domains, the results were consistent with PPIK theory.

Given these results, the question arises as to how interests and abilities are understood to develop within PPIK theory. Ackerman (1996) proposed that abilities and interests most likely develop in tandem, in a form of reciprocal determinism. Thus, when a person succeeds in developing competence in a domain, this will likely increase both confidence and the knowledge to which future knowledge can be added—thereby making future endeavours within this domain more successful. Likewise, an unsuccessful attempt to achieve competence might reduce confidence in this domain, and leave domain-relevant knowledge unchanged—making future attempts to increase competence less likely. This point re-iterates Cattell's (1963) argument against using "Process" and "Product" to designate Gf and Gc respectively—that knowledge acquisition can be affected by the present level of knowledge, not simply the "Process" component.

Knowledge. The fourth component of PPIK is intelligence-as-knowledge. Although conceptually similar to the broad Gc factor already discussed, PPIK makes two significant departures from the mainstream perspective on Gc. First, in line with Cattell's intuition, knowledge in adults is understood to be increasingly variegated and domain-specific when compared with adolescents. Once people leave the constraints of the school curriculum, Gc would become increasingly diverse, being influenced by occupation and interest factors. Moreover, Ackerman noted that the research of expertise provided a perspective consistent with PPIK, given that adults with expertise in particular domains do not "solve most real-world problems with brute force Gf processes of reasoning and rote memory" but instead rely on "specific knowledge that is brought to bear on a problem" (Rolfhus & Ackerman, 1999, p. 315). Thus, across the lifespan, people shift from relying on intelligence-as-process to intelligence-as-knowledge abilities.

Second, the essence of Gc in adults is understood to include domain-specific knowledge, not simply verbal ability. Ackerman and Rolfhus (1999) assessed Gc in an adult population, and reported that verbal ability predicted knowledge in some domains, but not others. Having partialled out a factor for general ability (the shared variance between verbal, spatial, and numerical abilities) using a Schmid-Leiman rotation (Schmid & Leiman, 1957), they reported that verbal ability correlated significantly with various knowledge domains. However, the correlations were not uniform, ranging from $r = .15$ with geography to $r = .64$ with world literature, while the other correlations were spread between figures, most being salient ($r > .3$ for 14/20). Thus, Ackerman and Rolfhus (1999) concluded that intelligence-as-knowledge was related to verbal ability in adults, but was not identical with it.

This shift in the conception of Gc, from simply verbal ability to including diverse knowledge, allowed a more nuanced assessment of whether young adults really were more intelligent than middle-aged adults. This longstanding issue had been raised by the developmental trajectory of Gf compared with Gc. As reported by Schaie and Strother (1968), cross-sectional results have suggested that younger participants outperform older participants in most domains of intelligence, while the longitudinal data have suggested that most abilities are well-retained (or even increased) up until about 60 years of age. Ackerman and Rolfhus (1999) attributed this apparent anomaly to reliance on the psychological method of Binet and Simon when measuring Gc. Instead, Ackerman and Rolfhus (1999) compared young adults (18–27 years) and mature adults (30–59 years) for knowledge across the 20 identified knowledge domains, reporting that mature adults on average knew more in every domain except for chemistry, which was not significantly different between groups. On this basis, they concluded that intelligence-as-knowledge provided a better account of the nature of adult Gc than the traditional approach. This led Ackerman (2000) to label domain-specific knowledge as the "dark matter" of adult intelligence—knowledge that is difficult to measure directly, but which exerts an influence on its environment.

Another issue this approach allows to be assessed is the presence of a general factor across these knowledge domains. Rolfhus and Ackerman (1999) conducted exploratory factor analysis across 20 knowledge domains, and identified four first-order factors (in addition to a single second-order factor), which they labelled Humanities, Science, Civics, and Mechanical. Of the variance explained at the test level, the second-order factor across these domains accounted for approximately 60% of that variance, while the first-order factors accounted for the remaining 40%. This finding suggests both that all knowledge domains are affected by a general knowledge factor, and that they cluster in a way which supports Holland's types. Therefore, despite the proposed differentiation of knowledge domains when assessed in adults, it appears that a significant general knowledge factor remains.

Finally, despite appearances, PPIK does not clearly state "where to put the 'causal arrow'" (Ackerman & Rolfhus, 1999, p. 325) in the relationship between knowledge, interests, and personality. It could plausibly point from interests to knowledge, but it could also point from knowledge to interests. Perhaps it is best to view their relationship as reciprocal, at least until future research can test this question more robustly (Rolfhus & Ackerman, 1999).

Relationship of PPIK with Cattell's Investment Theory

Ackerman acknowledged that PPIK "draws heavily" (1996, p. 237) on Cattell's framework, resulting in numerous similarities. Despite this overlap, however, Ackerman argued that PPIK departed from Cattell's investment theory in three significant ways, quoted in full:

1. General Intelligence as two broad factors (process and knowledge), rather than Gf and Gc, but closer to Hebb's notions of Intelligence A and Intelligence B.
2. To the degree possible, as revealed by metaanalysis and our own recent research, explicit representation is provided for a small set of personality factors and interest factors as related to intelligence and adult intellectual development.
3. Representation of adult intellectual knowledge and skill as complexes, for which different individuals may demonstrate very little overlap (e.g., the knowledge structures of a physicist may have little in common with the knowledge structures of a historian). (1996, pp. 237-8).

We shall assess these departures in turn.

First, although Ackerman preferred the labels Process and Product, we may ask what this difference in terminology has meant in theory and practice. Cattell's investment theory clearly implies that Gf corresponds to processing ability, and that Gc corresponds with the product of such processing. Moreover, Hebb's (1942) distinction between intelligences A and B was recognised by Cattell as the same as his distinction between Gf and Gc. Thus, despite the different labels, Cattell means by Gf essentially what Ackerman means by Process, and by Gc essentially what Ackerman means by Product. Ackerman has operationalised Process by using what are mostly traditional measures of Gf—except for some of his research before his proposal of PPIK (1996), which included speed of processing measures as they related to skill acquisition (e.g. 1988). Because it is a change in the label but not the content, we might wonder whether this aspect of PPIK is as distinctive as Ackerman suggests.

However, Ackerman's research agenda has provided a more detailed perspective on the Product component, particularly his demonstration that interest in various domains predicted knowledge in those domains—consistent with the theory that interest directs investment, resulting in domain-specific knowledge. This approach clarified Gc as being defined not just by verbal ability, but also by knowledge. Thus, his identification of intelligence as Process and Product as a departure has some substance, but more in terms of Product than Process abilities.

Second, we turn to the place of personality variables in the investment process. More than once, Ackerman (1996) stated that Cattell's investment theory does not include personality variables. For instance, he wrote: "Also, although not specified in the discussion of the Investment Theory, Cattell did indicate some personality factors that are related to different domains of intellectual abilities" (p. 235). Moreover, in the same place Ackerman wrote: "Cattell also integrated interest influences (though not personality) into the configuration, but again the detail of specific relations is not provided" (1996, p. 235). We may agree with the second part of this statement, but not the first. First, Cattell (1987) devoted an entire chapter (12) to interactions between personality and ability. Second, Cattell's clearest statement on the subject confirms that he was fully cognizant of the relevance of personality variables to investment theory:

> As to the compositeness of crystallized general intelligence, one must recognize that the positive correlations arise not only from the widespread uniformity of the school curriculum – at least in the three R's – and the fact that different individuals are exposed to it for different numbers of years, but they arise also from dynamic causes, in the form of some children being more strongly interested in all that may be called intellectual matters and school achievement. Examined closely, these influences that are not g_f, and not length of learning in school, are themselves complex. The personality researcher will pry them apart into such demonstrated contributors as affectothymia (A factor), superego strength (G), strength of self-sentiment (Q_3), and so on. (1987, p. 143)

Thus, Cattell uses "interest" and "dynamic causes" to denote, among other things, "personality". Although he did not elaborate the influence of personality variables within the investment process in as much detail as he did for the influence of the school curriculum, for example, Cattell certainly considered personality variables in his approach. In this respect, Cattell's theory was more inclusive than Ackerman gave him credit for.

This leads us to ask what Ackerman has contributed to our understanding of investment. Rather than providing a wholly novel contribution, Ackerman's approach has differentiated "interest" and "personality" variables that Cattell simply termed "interest". We might say that Ackerman did for Cattell's "interest" variable what Cattell did for Spearman's *g*: he bifurcated a single entity into two and, in doing so, has provided a richer theoretical account. His subsequent research agenda has shown the relevance of both aspects for predicting domain-specific knowledge in adults (Ackerman, 2000; Ackerman & Rolfhus, 1999; Rolfhus & Ackerman, 1996, 1999).

Third, we consider Ackerman's position that knowledge exists in domains that may overlap very little with one another. Ackerman has successfully shifted attention from the apparent, broad factor that relates to verbal ability and knowledge to its more discrete, domain-specific components which relate to professional expertise and interests. However, understanding the existence of this broad factor, and why it gives way to domain-specific knowledge, requires investment theory's understanding of the school curriculum: if the school curriculum produces the Gc factor, then its absence would weaken this factor. Moreover, the research subsequent to Ackerman's formal statement of PPIK indicates that these knowledge domains are distinct, but still overlap, especially the finding of Rolfhus and Ackerman (1999) that a general factor derived from across knowledge domains explained substantial variance in each domain. This leads us to conclude that that knowledge is simultaneously broad and domain-specific. Therefore, although Ackerman labels this aspect of PPIK a "departure" from Cattell's investment theory, he might have labelled it more appropriately as an "extension".

Conclusion

Perhaps our overall assessment of PPIK depends on what Ackerman meant by "departure". If he meant "different" or "at odds with", then it may be an overstatement which exaggerated the originality of his own contribution. But if he meant simply that PPIK starts with investment theory and continues the journey from there, then there is much to be affirmed in both theories, as the former is fulfilled in the latter.

1.6 Assessment of Investment Theory

Introduction

We will now assess a selection of studies that have tested predictions that follow from investment theory. As the previous survey has shown, the investment theories of Cattell and Ackerman did not contradict one another in any substantial respect, but each provided particular details lacking in the other. However, their principal difference is that Cattell's model provides more detail for the investment process in adolescent populations, while Ackerman's provides more detail for investment among adults. Thus, some studies will be relevant to one, the other, or both theories. This survey does not aim to be comprehensive, but to assess the major research findings that relate to investment theory, and thus to establish whether investment theory remains a viable framework for future research. This survey specifically assesses subsequent research included here as it concerns the four predictions of investment theory that we identified earlier: (1) the relationship of *g* with Gf and Gc; (2) interpreting the broad Gc factor; (3) tests of Gf as a predictor of the growth of Gc; (4) the heritability of Gf and Gc. It will also consider (5) alternative models of intelligence and investment.

(1) The Relationship of *g* with Gf and Gc

As noted earlier, a significant prediction of Cattell's investment theory is that the relative loading of Gf and Gc on *g* will depend upon the homogeneity of the cohort in question. In other words, for populations that have a more similar upbringing, culture and learning opportunities, *g* should load more strongly on Gf than on Gc, while the opposite trend should appear for populations with less similar backgrounds.

This prediction has been tested using both adolescent and adult populations. For adolescent populations, Undheim and Gustafsson (1987) used three samples of Norwegian primary school students, aged 11, 13, and 15 years. They assessed a broad range of intelligence subtests which were used to calculate factors including Gf, Gc, cognitive speed (Gs), visual perception (Gv), and retrieval ability (Gr), and tested model fit using LISREL structural equation modelling. However, regardless of which age group they assessed, or which broad factors were assessed in the battery, *g* loaded upon Gf with near unity in each case. On this basis, the authors concluded that Gf is equivalent to the general factor of intelligence within such cohorts.

Valentin Kvist and Gustafsson (2008) conducted a complementary analysis using an adult population. They assessed the relative loading of *g* on measures of Gf, Gc, Gv, and Gs using three samples with different learning opportunities: Swedes (n = 2,358), European immigrants (n = 620), and non-European immigrants (n = 591). From Cattell's investment theory, the authors predicted that the relative loading of g on Gf would be stronger in path models which assessed each subgroup individually, than for models which assessed all three groups together. This prediction was supported; the analysis conducted on the combined sample reported that *g* loaded .83 on Gf, .80 on Gc .55 on Gv, and .61 on Gs—indicating that all loadings were far from unity. However, the relationship between *g* and Gf was near-perfect within each of the subgroups (.98 to .99), with *g* loadings on the other three second-order factors ranging from .80 to .37 (Swedes), .67 to .49 (European immigrants), and .63 to .38 (non-European immigrants). The authors concluded:

> This result provides support for the Investment theory, and for the hypothesis that Gf is equivalent to g. However, the results of this study also imply that the

> hypothesis of Gf–g equivalence only holds true when the subjects have had approximately equally good, or equally poor, opportunities to develop the knowledge and skills measured. (Valentin Kvist & Gustafsson, 2008, p. 433)

Subsequent research, therefore, has found substantial support for this prediction of investment theory.

(2) Interpreting the Broad Gc Factor

Since the investment theories of Cattell and Ackerman were proposed, researchers have not held to a unanimous position on the precise nature of Gc, disagreeing about two aspects. First is the question over the nature of Gc: is it a true factor that exerts an influence on its various subtests (the realist interpretation)? Or is it a statistical entity that forms from the application of Gf across various knowledge or language domains (the non-realist interpretation)? Second is the question of the content of Gc: is it composed primarily of verbal or factual knowledge?

Kan, Kievit, Dolan, and van der Maas (2011) assessed the nature of Gc using confirmatory factor analysis (CFA) on a dataset with a homogeneous population of male naval recruits ($N = 483$). They found that *g* and Gf were statistically indistinguishable, as were verbal comprehension and Gc. Their conclusions were that Gc is not an ability *per se* but is an outcome of applied verbal ability, and thus Gc is best understood from a non-realist perspective. They argued that this finding concerning Gc contradicted the notion within Cattell-Horn-Carroll (CHC) theory that Gc is a distinct ability, but broadly supported Cattell's investment theory—which they concluded remained a viable approach within intelligence research.

Concerning the content of Gc, Schipolowski, Wilhelm, and Schroeders (2014) assessed its relationship with verbal ability and declarative knowledge in a large-scale sample of German school students (*N* = 6,701) across different academic tracks. They reported that these two factors overlapped substantially (ρ = .91), but that each also possessed substantial unique variance, and concluded that verbal ability and knowledge are distinguishable facets of Gc. However, if researchers could not assess both, they suggested that measures of verbal ability should be preferred because it permits brief and reliable assessments. Moreover, they argued that the conclusion of Kan et al. (2011), that Gc was indistinguishable from verbal ability, was due to relying on a relatively narrow assessment of Gc, unlike their own study. It is difficult to compare these results directly, however, because Schipolowski et al. (2014) did not use a similarly homogeneous sample to that of Kan et al. (2011)—which the latter argued is a prerequisite to testing investment theory. Thus, in conclusion, the investment approaches of Cattell and Ackerman remain plausible avenues for research on the nature of Gc, because evidence supports the interpretation that it contains both verbal ability and knowledge.

(3) Tests of Gf as a predictor of the growth of Gc

Several studies have assessed whether the investment relationship can be observed over time, assessing participants through studies with longitudinal designs. Ferrer and McArdle (2004) used dynamic modelling to assess the influence of Gf upon both Gc and academic achievement across time in participants 5-24 years old. They found mixed support for investment theory; although Gf did not predict changes in Gc (inconsistent with investment theory), Gf did predict changes in performance on measures of quantitative abilities and academic knowledge (consistent with investment theory). The authors concluded that Gf was the leading predictor of changes in variables related to academic knowledge, but that the relationship between Gf and Gc may be more complex than Cattell specified.

Thorsen, Gustafsson, and Cliffordson (2014) assessed Gf as a predictor of Gc using data obtained from a sample of Swedish school students (N = 9,002) with measures obtained at grades 3, 6, and 9. They assessed both Cattell's investment theory and the Encapsulation hypothesis: that the effects of Gf will become "encapsulated" within Gc, with the result that Gf will only influence specific outcomes such as school grades *indirectly* through its influence on broad Gc. Results indicated that the influence of Gf upon Gc increased across the years of schooling, but also that Gf influenced school grades only indirectly through its influence on Gc. They concluded that this study provided support for investment theory, and for the Encapsulation hypothesis. Moreover, Soares, Lemos, Primi, and Almeida (2015) reached similar conclusions using N = 284 Portuguese students: grade 7 AP was the best predictor of grade 9 AP, and the influence of cognitive ability measured in grade 7 on grade 9 AP was mediated by grade 7 AP. These studies provide some support for the investment process as it relates to academic outcomes.

Christensen, Batterham, and Mackinnon (2013) assessed whether higher levels of Gf predicted accelerated acquisition of Gc, measured by vocabulary knowledge (assessed by the Spot-the-Word test; Baddeley, Emslie, & Nimmo-Smith, 1993) in a population-representative sample of young adults. The authors concluded that this study showed no support for investment theory; although participants with Gf had correspondingly higher levels of Gc, there was no evidence of an accelerated acquisition of Gc. However, a potential oversight of this study involved the participants, being a community sample initially aged 20-24 years, whose vocabulary knowledge was re-assessed four and then eight years later. As noted earlier, Cattell specified that the education system is the common link between Gf and Gc. However, because this cohort was beyond the age of compulsory education, these variables would be expected to behave differently than for a cohort still undergoing compulsory education. Therefore, it is possible that this conclusion was based on an interpretation of investment theory that did not take full account of the parameters within which Cattell expected investment to operate.

Rindermann, Flores-Mendoza, and Mansur-Alves (2010) assessed investment theory in two groups of adolescents: a Brazillian sample (*N* = 833, aged 7-15) with below-average ability (IQ *M* = 92, *SD* = not reported), and a German sample (*N* = 722, aged 11-19) with above-average ability (IQ *M* = 118, *SD* = not reported). They assessed Gf and Gc measured two years apart, and reported that both Gf and Gc exerted similar influence on the latter measure of Gc—inconsistent with investment theory. However, parental SES and education predicted Gc more strongly than they predicted Gf—consistent with investment theory's view of the malleability of Gc.

In evaluating this research, it remains possible that not every study assessing investment theory assesses hypotheses that follow from investment theory (see also McArdle, Hamagami, Meredith, & Bradway, 2000 on this issue). For instance, although Schmidt and Crano (1974) argued that the influence of Gf upon Gc should be discernible through cross-lagged correlations, Gustafsson and Undheim (1992) argued that this may not necessarily be the case. Therefore, the mixed results concerning the influence of Gf on Gc may result from misunderstandings of investment theory in some cases, a real lack of support in others, or the possibility that the process of investment in the real world is more complex than the theory—at least from the perspective of some researchers—has given it credit for.

(4) The Heritability of Gf and Gc

Investment theory suggests that heritability estimates should be higher for Gf than Gc, because the former is understood to be the more innate, biological capacity for perceiving relationships, while the latter is more affected by the environment. However, in a very significant study, Kan, Wicherts, Dolan, and van der Maas (2013) assessed the heritability of Gf and Gc using data from 23 twin studies assessing adults and children. Here, the cultural load of intelligence subtests was assessed by the proportion of items in intelligence subtests which were modified when being adapted for use in different countries. The authors reported two novel, important findings: (1) subtests with a stronger cultural load possessed stronger heritability coefficients than those with weaker cultural load, and (2) a subtest's cultural load correlated substantially and positively with its loading on the statistical general factor, indicating that, in the words of the paper's title, "the more heritable, the more culture dependent". The authors noted that these findings are not consistent with investment theory, but make sense when viewed from the perspective of models that include the contribution of genotype-environmental covariance. This recent evidence concerning the heritability of Gf and Gc indicates that the process by which Gc develops is more complex than investment theory has suggested, and may require the addition of genotypic-environmental covariance.

(5) Alternative Models of Intelligence and Investment

Lastly, several researchers have proposed either modifications to investment theory, or alternative models of intelligence which they argue fit the data more closely.

In the former category, Schweizer and Koch (2002) included learning as a mediating variable in the relationship between Gf and Gc. They reported that their modified investment model was supported in the sample of younger participants (aged 19-23 years), but not in the older sample (24-30 years). Although they explained this difference in terms of Cattell's expectation that the investment process weakens considerably as people age, due to professional specialisation, this explanation is questionable because both samples were obtained from the same university course and were thus past the age of compulsory education.

In the latter category, the first of two models we consider here has argued that the structure of intelligence is verbal, perceptual, and image rotation (VPR) rather than fluid and crystallised. Johnson and Bouchard (2005) noted that relatively little work had assessed the fit of CHC and extended Gf-Gc theories, compared with other approaches, and proposed VPR theory as an alternative model for intelligence. This model retains an overarching *g* factor, and places image rotation (R) alongside verbal (V) and perceptual abilities (P). Using a heterogeneous sample and SEM, the authors reported that VPR theory fitted an assortment of 42 test batteries better than did the two alternative theories. Furthermore, Major, Johnson, and Deary (2012) followed up this line of enquiry by assessing the fit of these three models, using a representative study of American high school students from the 1960s named Project TALENT. Major et al. (2012) obtained the same broad result: VPR theory obtained closer fit statistics than did either CHC or extended Gf-Gc theory. The authors noted that "No study to date has contradicted this conclusion" (Major et al., 2012, p. 555).

In response, two comments are in order. First, although VPR theory achieved better fit statistics than the alternatives, the differences were comparatively minor and these results may not constitute a major theoretical advance. Second, and perhaps more importantly, a modest rearrangement of the hierarchy of human abilities would not likely make redundant the developmental account that investment theory provides. Because the factors in the VPR model are conceptually very close to their CHC and extended Gf-Gc counterparts, their existence and interrelationship still require a developmental explanation. Therefore, even if researchers were to adopt wholeheartedly the VPR framework for subsequent research, the essence of investment theory could probably be retained with little modification.

We turn now to the second of the two alternative models advanced as providing a better fit to pre-existing data. Termed OFCI (Openness-Fluid-Crystallized-Intelligence), this model was proposed as an alternative investment framework by Ziegler, Danay, Heene, Asendorpf, and Bühner (2012). The authors noted that this model is not proposed as a comprehensive alternative to PPIK (or Cattell's investment theory, presumably), but is concerned with the narrow question of the relationship between Gf, Gc, and Openness to Experience. It provides two perspectives on how these variables are related: the immediate performance perspective, and the developmental perspective. We survey these in turn.

The immediate performance perspective states that variables Gf, Gc, and Openness to Experience can interact with one another as they predict variance in task performance, such as academic achievement. For instance, a higher level of intellectual curiosity might allow a student to make more use of his intellectual potential in class, while a lower level of curiosity might preclude another equally capable student from doing the same. Thus, Gf and Openness might interact significantly to predict performance within immediate situations (Ziegler et al., 2012).

From its developmental perspective, OFCI accepts Cattell's investment theory as a starting-point, with its position that Gf influences Gc developmentally. However, OFCI notes that Gf and Openness overlap moderately, and incorporates two complementary hypotheses that might account for this overlap. The *environmental success hypothesis* states that those with initially higher levels of Gf have more successful experiences in any environments they encounter, increasing their Openness to Experience subsequently. The *environmental enrichment hypothesis* states that those with initially higher levels of Openness are more likely to seek out environments that are stimulating and challenging, increasing their Gf subsequently.

Two research papers have assessed aspects of the OFCI model, in younger and also older participants. Ziegler et al. (2012) assessed both the immediate performance perspective and the developmental perspective of OFCI using a population of psychology students (n = 180, age m = 24). The authors found the expected evidence for an interaction between Gf and Openness in the prediction of Gc, and concluded that this supports OFCI specifically and Cattell's idea of investment more generally. They also assessed the developmental perspective with longitudinal data from 174 adolescents, assessed at 17 and 23 years of age for several variables, including Gf, Gc, and Openness to Experience. They found evidence for the environmental enrichment hypothesis, reporting that Openness predicted changes in Gf, but they did not find support for the environmental success hypothesis—an outcome that they argued was due to an insufficient sample size. Moreover, Ziegler, Cengia, Mussel, and Gerstorf (2015) assessed OFCI in an older population (initial n = 516, 70-103 years of age), where higher levels of Gf might be expected to protect against Gc declines in a population that is experiencing cognitive decline generally. They found support for environmental success and enrichment, and investment theory. Overall, the two studies assessing investment theory within the OFCI model have found support for it.

Conclusion

From this selective review of research since Cattell proposed investment theory we see that the theory has received mixed support. First, its prediction of a strong relationship between g and both Gf and Gc as a function of homogeneity has been supported. Second, Cattell's and Ackerman's multi-dimensional perspectives on the definition of Gc—whether it is primarily verbal ability or knowledge-based—have found support, though researchers have disputed which is primary. Third, although studies that have assessed whether Gf is a leading indicator of changes in Gc have reached different conclusions (when the findings regarding the OFCI model are also considered), this may reflect different methodologies. This work has suggested that the relationship may be different for typical measures of Gc compared with Gc measured by academic outcomes. Fourth, studies which have assessed the heritabilities of Gf and Gc have concluded that Gc is more heritable than Gf, which contradicts Cattell's predictions, and suggests that genotypic-environmental covariance may have been overlooked in this model. Fifth, some researchers have added additional elements to Cattell's model (e.g. learning), or proposed alternative models (e.g. VPR), some of which have incorporated and found support for his essential ideas (e.g. OFCI).

1.7 Conclusion

As the foregoing review makes clear, investment theory has been highly influential in the history of intelligence research. Cattell retained Spearman's notion of a general ability, but suggested it be subdivided into fluid and crystallised abilities, and proposed investment theory to explain their relationship, with the education system as an essential element. In his PPIK model, Ackerman took the essential insights of Cattell's model and reformulated these as they applied to adult populations. Subsequent research has assessed various predictions of investment theory and, while support has not been without question, with some aspects requiring modification, such support has been sufficient to endorse investment theory as a viable platform on which to base future research. This conclusion is also vindicated by the fact that research on investment theory has regularly appeared since it was first proposed some 70 years ago until the present day.

2 Other Perspectives on Curiosity

2.1 Introduction

Chapter 1 introduced the concept of intellectual curiosity as it relates to the investment theories of Cattell and Ackerman. There are, however, alternative perspectives on curiosity that come from different domains of research, and the aim of this chapter is to survey these other perspectives. This chapter is presented under three main headings: *The State Approach*, *Precursors to the Trait Approach*, and *The Trait Approach*. The measures included here have been selected because they share a lineage, and address several broad distinctions within the domain of curiosity. Other measures of IC including Openness to Ideas (Costa & McCrae, 1992b) and the Need for Cognition (Cacioppo & Petty, 1982) are addressed in the next chapter.

2.2 The State Approach

Sokolov

Evgeny Sokolov (1920—2008) was a Russian scientist whose research contribution included 12 books and over 400 articles—many of which have not been translated into English (Spinks, Näätänen, & Lyytinen, 2008). His research spanned several disciplines, including physiology, psychology, and neuroscience, and he contributed more to understanding the orienting reflex (or orienting response; OR) than anyone else in the 20th century. Surveying research on the OR is important because this phenomenon provided a point of departure for two other lines of research we shall cover shortly: preference for novelty (Fagan), and curiosity (Berlyne).

Broadly, Sokolov defined the OR as “a set of reactions evoked in humans and animals by a novel stimulus” (Sokolov, 2001, p. 10978). These reactions include observable behaviors (directing sensory organs at the stimulus), but far more abundant are the discrete reactions, including changes in heart rate, blood flow, neural activation, skin conductivity, and event-related potentials (Sokolov, 2001), which Sokolov continued to study until his death (Spinks et al., 2008). He also documented the tendency for the OR to habituate when the stimulus was presented repeatedly (Sokolov, 1963)—a tendency that reflects learning, and that research on "preference for novelty" would later rely upon.

The OR was first described by Senechov, an earlier Russian physiologist whom Pavlov described as "the Father of Russian physiology". Moreover, Pavlov himself also investigated this phenomenon, clearly defining it and explaining its functions:

> It is this reflex which brings about the immediate response in man and animals to the slightest changes in the world around them, so that they immediately orientate their appropriate receptor-organ in accordance with the perceptible quality in the agent bringing about the change, making full investigation of it. The biological significance of this reflex is obvious. If the animal were not provided with such a reflex its life would hang at every moment by a thread. (Pavlov, 1927, p. 27)

Here, Pavlov argued that the OR has survival value for animals because it directs them toward imminent threats. However, he followed this by suggesting that the OR possesses a unique significance for human history:

> In man this reflex has been greatly developed in its highest form by inquisitiveness-the parent of that scientific method through which we hope one day to come to a true orientation in knowledge of the world around us. (1927, p. 27)

While not all researchers would concur with Pavlov's far-reaching interpretation, probably most would agree that the OR orients humans to stimuli of interest, and is thus a precursor to the form of curiosity that seeks information and understanding.

Fagan

Research on the "preference for novelty" was pioneered by Fantz, who studied this tendency using infant chimpanzees (1956) and humans (1964)—the approach that Fagan developed further. To assess preference for novelty, infants were initially shown an image, and subsequently shown the original image alongside a novel image. If the infant spent more time looking at the novel image, this indicated a preference for novelty. This preference was explained in terms of learning: an infant who preferred a novel image thereby showed that he had recognised the original image (Fantz, 1964).

Fagan (1941–2013) spent much of his research career assessing evidence of memory in young humans, especially the existence of preference for novelty and its ability to predict functioning later in life. His early research included comparing digit-span memory in children with normal or impaired cognitive ability (Fagan, 1966), and developing approaches to assessing preference for novelty in infant humans (Fagan, 1970). He demonstrated that infants can perceive colour (Fagan, 1974), can recognise the same face when photographed from different angles (Fagan, 1976), and can recognise the same face despite being presented with a similar face during a retention interval (Fagan, 1977b). On the basis of this research, Fagan (1977a) proposed an attention model of infant recognition, comprised of two components: (1) the orienting response, and (2) the fixation response. These two theoretical components are captured by the measure of the infant's preference for novelty: "Both the attentional and the fixation responses are covert; the only observable behavior is the actual amount of time spent viewing the two targets" (1977a, pp. 346-7).

Preference for novelty has been especially significant, however, as a marker of intelligence. Previously, measures of sensorimotor skills had been used to assess infant intelligence—influenced by the perspective of Piaget (1952)—but proved to be poor predictors of intelligence later in life (Fagan, 1981). This lack of a relationship led some theorists to surmise that infant intelligence was discontinuous with adult intelligence (e.g. Bayley, 1955). However, Fagan and McGrath (1981) assessed preference for novelty in a group infants four to seven months old, and obtained correlations with verbal intelligence of r = .37 at four years of age, and .57 at seven years. The authors also noted that these correlations were virtually unaltered when a proxy of SES (parental education) was partialled out, and were probably underestimates of the true correlations due to restriction of range and measurement error. Moreover, subsequent longitudinal research has shown preference for novelty to predict adult intelligence and academic achievement (Fagan, Holland, & Wheeler, 2007); while a similar line of enquiry has shown that a similar index of infant cognition to predict executive function at 11 years (Rose, Feldman, & Jankowski, 2012). Taken together, this research has provided powerful evidence that a substantial proportion of adult intelligence can be predicted from measures obtained during infancy of basic processes, indicating that the development of intelligence is continuous from birth (or at least early infancy) to adulthood.

This evidence raises the question of the basis for this continuity. Fagan (1984) noted that "The ability to detect similarities among otherwise diverse stimuli, for example, is a basic intellectual process" (p. 3), which he understood to be "information processing". On the assumption that individuals differ in their speed of information processing, Fagan noted that "what we measure on an intelligence test is the result of the interaction of speed of knowledge processing with the environment the person has been allowed to process" (1984, p. 5). This view is consistent with the investment theory of intelligence surveyed in the previous chapter, in the sense that some early basic characteristic is held to influence how cognitive abilities develop. Specifically, Fagan held that information processing ability was the basis of the continuity of intelligence across the lifespan, and therefore of general intelligence itself (Fagan, 2000).

For our purposes, it is noteworthy that the preference for novelty construct bears a striking similarity to the concept of curiosity as it appears in other research contexts. Although the survey of Berlyne's contribution to curiosity research will make this resemblance clearer, the preference for novelty appears to assess curiosity for infants. Moreover, most significant is the connection between infant curiosity and adult intelligence. Given that subsequent research has sometimes sharply distinguished the domains of intelligence and personality—where personality is sometimes defined as variables that have no relationship with intelligence—it is ironic that the best predictor of adult intelligence from infancy is a trait that has come to be associated with personality variables! Although the distinction between intelligence and personality variables in adults has proved useful, and has improved prediction, accounting for far more variance in important life outcomes than either could alone, research on preference for novelty indicates that curiosity and intelligence may be indistinguishable for infants. The significance of this observation will be explored more fully in the Conclusions chapter.

Berlyne

Daniel Berlyne (1924—1976) was a British-Canadian researcher who completed his PhD at Yale University in just in two years (while teaching full time in the second). After this he returned to Britain, travelled to California, and spent time in Switzerland studying with Jean Piaget (Konečni, 1978). However, despite the fact that Piaget's subsequent influence has endured, his influence on Berlyne's research appears to have been slight (Konečni, 1978). Later, he worked at the University of Toronto, Canada, until his untimely death from prolonged illness (Konečni, 1978).

Berlyne's career has been described as an effort to explain "a broad array of human and animal behaviour" with "a small number of motivational principles" (Konečni, 1978, p. 134). While his most significant contribution to research revolved around curiosity, starting with his first publication (Berlyne, 1949) and reaching its high-point with his book *Conflict, Arousal, and Curiosity* (1960), he also researched aesthetics extensively during the last decade of his life, an effort that effectively opened up this area for future researchers (Konečni, 1978, 1996).

Like most researchers, Berlyne's work was indebted to his predecessors and contemporaries, especially Pavlov and Fantz. This was especially so regarding the orienting reflex as it related to curiosity variables. Given the close connection between the orienting reflex and exploratory behavior, Berlyne assessed whether variables shown to affect the level of perceptual curiosity (explained below) also affected the orienting response. He found this to be so, and concluded that complexity and novelty "elicit the investigatory reflex" (Berlyne, 1958, p. 295). Therefore, people are more likely to orient towards objects that are novel and complex, and such objects will command their attention for longer than for objects that are familiar and less complex. Berlyne also observed the tendency for responses to habituate after repeated exposures, and suggested the following hypothesis: "*As a curiosity-arousing stimulus continues to affect an organism's receptors, curiosity will diminish*" (Berlyne, 1950, p. 74, italics in original). Thus, alongside Fantz his contemporary, Berlyne's research had identified the elements necessary to assess the construct of preference for novelty (Fagan, 2011), and the process by which this took place—novelty as a drive, leading to investigation, leading to habituation.

Berlyne's contribution to curiosity research involved empirical work inducing curiosity in research participants, and distinguishing between varieties of curiosity. In his early work, Berlyne (1949) argued that research to that time had not grappled sufficiently with why people become absorbed in activities "whose biological necessity is not obvious, such as building model boats or solving cross-word puzzles" (p. 189), and therefore he began a program of research to discover what would predict such engagement. He also argued that novelty was a key factor in piquing interest, which led to exploring the object of interest, a process common to humans and other animals such as rats (Berlyne, 1950). While Pavlov saw a drive toward human civilisation in the orienting reflex, Berlyne saw the same drive in the human desire for novelty:

> An active striving to encounter new experiences, and to assimilate them when encountered, underlies a huge variety of activities highly esteemed by society, from those of the scientist, the artist and the philosopher to those of the polar explorer and the connoisseur of wines. (Berlyne, 1950, p. 68)

However, it was not mere novelty that was most powerful, but novelty where this is not expected, such as in an unexpected feature of an otherwise familiar object (Berlyne, 1950).

Berlyne (1950, 1954, 1966) distinguished curiosity along two dimensions, and these distinctions survive (with some variation) to the present day. His first distinction was between *perceptual curiosity* (PC) and *epistemic curiosity* (EC); that is, distinguishing curiosity that is aroused by sensory information from curiosity aroused by the realm of ideas—similar to the distinction between Openness to Experience and Openness to Ideas in the NEO-PI-R (Costa & McCrae, 1992b). These drives can be defined more extensively positively and negatively; by what behaviour they produce, and by the effect of this behavior on the underlying drive. Positively, PC is the "curiosity which leads to increased perception of stimuli", while EC is the curiosity "whose main fruits are knowledge" (Berlyne, 1954, p. 180). Negatively, PC is "a drive which is reduced by perception", while EC "is reduced by the acquisition of knowledge" (Berlyne, 1957, pp. 399-400). While both human beings and other animals experience PC, EC has been argued to be to humans (Berlyne, 1954; Loewenstein, 1994).

Berlyne's second distinction was between *diversive curiosity* (DC) and *specific curiosity* (SC), where the former arises from boredom, while the latter arises from a puzzle or knowledge deficit (1966). He suggested that these two classes of exploratory habits serve biological needs: specific curiosity arises when an animal "is disturbed by a lack of information, and thus left a prey to uncertainty and conflict" (1966, p. 26), whereas diversive exploration allows an animal to maintain an optimum level of physiological arousal (1966). Moreover, these two dimensions can combine to produce four distinct categories of curiosity: perceptual curiosity—specific (PC/S), perceptual curiosity—diversive (PC/D), epistemic curiosity—specific (EC/S), and epistemic curiosity—diversive (EC/D; Loewenstein (1994) provides some useful examples of each).

In summary, Berlyne's contributions to curiosity research have been enduring. His rich theoretical accounts have inspired and informed many researchers, and his main distinctions between forms of curiosity have also endured—especially concerning EC, which has appeared (with adjustment) in the research of Litman and Mussel. However, as researchers have noted, Berlyne did not assess curiosity as a dimension of personality (Litman & Spielberger, 2003), which would become the dominant approach to subsequent research in this field.

2.3 Precursors to the Trait Approach

Although Berlyne broadly measured "state" curiosity, while Litman employed a "trait" approach, there were several developments in between these two approaches, including the development of scales to measure both constructs, such as the State-Trait Curiosity Inventory (Spielberger, Peters, & Frain, 1976).

Earlier in the 1970s, Langevin (1971) distinguished between Berlyne's conception of curiosity as a motivational state (leading to exploratory behaviour) from the individual difference approach. To assess whether curiosity was a unitary or multifaceted construct, he factor analysed several state and trait measures of curiosity. He reported evidence for curiosity factors corresponding to "breadth of interest" and "depth of interest"—roughly equivalent to Berlyne's distinction between diversive and specific curiosity—and that, although the factors of curiosity were distinct from intelligence, their intercorrelations were quite low, suggesting that measures of curiosity should therefore be developed more thoroughly to capture their distinctness. Furthermore, Langevin (1976) also conducted a follow-up study assessing the psychometric properties of self-report and performance (i.e. behavioural) measures of curiosity. His major conclusions were much the same: while both approaches overlapped with discriminant variables (measures of social desirability and intelligence), self-report scales did so more, and therefore needed further development to capture their intended constructs more clearly.

Roughly a decade later, Olson, Camp, and Fuller (1984) compared scores on the Need for Cognition scale (NFC; Cacioppo & Petty, 1982) with several other measures of curiosity. NFC correlated $r = .55$ and $r = .67$ with the Melbourne Trait Curiosity scale and the Spielberger Trait Curiosity scale respectively, and $r = .45$ and $r = .55$ with the Melbourne State Curiosity scale and the Spielberger State Curiosity scale respectively. Although NFC correlated more strongly with the trait than state measures—unsurprisingly, given that NFC is intended as a trait measure—this suggests that state and trait approaches share a large overlap. Moreover, Olson and Camp (1984) factor analysed several curiosity scales, including state and trait measures, and reported evidence for a general curiosity factor. Obviously, these conclusions were not easily reconciled, and more research on the state-trait distinction was needed.

2.4 The Trait Approach

Litman

Jordan Litman has been a highly-active researcher in the domain of curiosity in recent years. Although Berlyne's main contributions were his stimulating theoretical account of curiosity, and his use of "state" or possibly more "objective" measures of curiosity, Litman's research has rigorously transformed these constructs into personality scales, while offering theoretical advances along the way. We will assess his contribution under three headings: (1) definitions of curiosity, (2) research on PC, SC, and EC, and (3) theoretical advances.

Definitions of curiosity. Because measures of curiosity overlap, it is useful to first define them. In Litman's research, both EC and PC remain largely unchanged from Berlyne's perspective. Litman, Collins, and Spielberger (2005) defined EC as being "stimulated by intellectual uncertainty, and motivates behaviors such as asking questions in order to acquire knowledge"; and defined PC as being "aroused by the presentation of new or unusual sights or sounds' and as motivating 'exploratory behaviors such as visual inspection or attentive listening" (Litman, Collins, et al., 2005, p. 1124). Thus, EC and PC are expressed through information-seeking behaviour. Litman, Collins, et al. (2005) have also developed a measure of sensory curiosity (SC). Although SC might appear to be identical with PC, the difference is that PC is a desire for understanding *prompted* by sensory information, whereas SC is curiosity for sensory experiences *themselves* (Litman, Collins, et al., 2005). Moreover, although SC might also appear to be similar to sensation seeking, SC "does not involve the physical or social risk-taking or the desire for intense emotional arousal" characteristic of sensation seeking (Litman, Collins, et al., 2005, p. 1125).

Not only has Litman moved Berlyne's conceptions of curiosity into the domain of individual differences, but he has also redefined "diversive" curiosity as a "feeling-of-interest" (CFI or I-type), and "specific" curiosity as a "feeling-of-deprivation" (CFD or D-type). We shall survey four reasons for these redefinitions. First, as Loewenstein (1994) observed, Berlyne proposed the "diversive" and "specific" distinction as it related to exploratory behaviour rather than curiosity *per se*, and therefore this distinction would need to be established properly as it concerned curiosity itself (Litman, 2008). Second, the term “diversive” is somewhat ambiguous: it might be understood to indicate either breadth of interest, or curiosity that serves to alleviate boredom. This ambiguity underscored the need for a clearer conception of this dimension of curiosity (Litman, 2008). Third, in addition to the “interest” dimension of curiosity, Berlyne’s (1954) account emphasised that being deprived of information was also a strong force that motivated exploratory behaviour. This “deprivation” dimension had been neglected by curiosity research, but showed potential to be important within the broad domain of curiosity (Litman & Jimerson, 2004). And fourth, “interest” and “deprivation” dimensions of curiosity focus more directly on the subjective experiences associated with these constructs, whereas “diversive” and “specific” constructs do this less clearly. Given the salience of emotional states within theoretical accounts for curiosity, terms that expressed these different experiences were to be preferred (Litman, 2008). Therefore, on the basis of these and other considerations, Litman and colleagues re-defined the diversive and specific components of curiosity as “interest” and “deprivation” factors, respectively.

Research on PC, SC, and EC. To begin, an important aspect of this research was to demonstrate that the dimensions of curiosity that Berlyne outlined were distinct from one another when assessed as personality traits. Litman and Spielberger (2003) used an initial pool of 56 items worded to capture either EC and PC, including their proposed diverse and specific components, to assess this. Exploratory factor analysis suggested a two-factor solution, with the substantial correlation between EC and PC (r = .56) indicating overlap but not identity. Moreover, following rotation, the items also loaded onto diversive and specific components, indicating that this distinction is also meaningful from a personality perspective.

PC has also been researched more extensively. Collins, Litman, and Spielberger (2004) demonstrated that 33 items worded to measure PC loaded onto a broad factor of PC, and also loaded onto diversive and specific components following rotation. Moreover, the resultant factors showed moderate correlations with scales measuring sensation seeking and knowledge, indicating that PC involves curiosity for both knowledge and experiences. The divergent validity of the PC scale from other personality variables was established by demonstrating small and generally non-significant correlations with trait measures of anxiety, anger, and depression.

Moreover, Litman, Collins, et al. (2005) validated a measure of sensory curiosity (SC) and assessed its distinctness from EC and PC, and from sensation seeking. They reported convergent validity among the three curiosity measures—correlations between SC and both EC and PC were stronger than correlations between sensation seeking and both EC and PC—and discriminant validity was demonstrated by minimal correlations between SC and measures of trait anxiety, anger, and depression. The authors proposed that that EC, PC, and SC were distinct but somewhat related measures that might be overarched by a broad curiosity construct (Litman, Collins, et al., 2005).

Notwithstanding the research conducted on PC and SC, Litman's most extensive contribution has been his development of EC scales. In a series of four studies, Litman (2008) developed and validated a more concise measure of EC intended to differentiate I-type and D-type curiosity more clearly. These measures of the I-D (or wanting-liking) model of curiosity were then tested in a subsequent study

(Litman, 2010) as they related to measures of ambiguity tolerance (MacDonald, 1970) and need for closure (Webster & Kruglanski, 1994). The I-D model would predict that higher I-type curiosity would correspond with higher tolerance for ambiguity, and that higher D-type curiosity would correspond with a stronger need for closure. This is what Litman (2010) found; the study's findings were consistent with these predictions.

Litman (2008) and Litman (2010) used student populations, but these same scales have been validated in non-student populations (Litman, Crowson, & Kolinski, 2010), and therefore the conceptual distinction between I-type and D-type curiosity has strong empirical support (see also Litman & Mussel, 2013). Moreover, Lauriola et al. (2015) conducted a cross-cultural study (using Italian, American, and German undergraduate students) using the I-D model of EC, and assessed its relationship with variables measuring self-regulation. They concluded that I-type curiosity overlaps with "*carefree* intellectual exploration", while D-type EC "orients individuals to apply cognitive resources *judiciously*" (Lauriola et al., 2015, p. 206, italics in original)—concepts consistent with the studies already surveyed here. Finally, Piotrowski, Litman, and Valkenburg (2014) developed a scale to measure NFC in young children aged 3 to 8 years as measured by parents' reports, and reported evidence for the I-D model in this demographic.

Additionally, it should be noted that D-type curiosity (i.e. CFD) has been assessed more extensively in its own right. Litman and Jimerson (2004) noted that while several scales had been developed to measure I-type curiosity, none measuring D-type curiosity had yet appeared. They therefore developed a 27-item questionnaire, and obtained evidence for a strong general factor corresponding to D-type curiosity, with three meaningful subfactors (labelled *intolerance*, *competence*, and *problem-*

solving) emerging following rotation. This outcome therefore provided further evidence of the existence and nature of this dimension.

Theoretical advances. Along with the refined and validated scales measuring EC, PC, and SC, Litman and colleagues have also provided a fresh theoretical account from the perspective of brain systems to explain the existence of these factors of curiosity. Since Berlyne's time, evidence that the drive reduction and optimal arousal theories could not explain easily—such as the observation that organisms will often engage in behaviour to increase levels of arousal; and that physiological levels of arousal show only weak correlations with emotions and behaviour—increasingly led to many researchers to abandon these models as they underpinned accounts of curiosity (Litman, 2005). Obviously, this meant that new explanations were required. Litman (2005) theorised that an important aspect of the I-D model of curiosity is that new knowledge might be expected to increase pleasurable feelings (I-type) or decrease unpleasant feelings associated with uncertainty (D-type), depending on the recipient's context (Litman, 2005). The differences between these types of behavior have been suggested to correspond to the opioid "liking" and dopaminergic "wanting" systems in the brain, for which there is evidence of differential patterns of brain activity (Litman, 2005). Importantly, both systems may be activated at the same time, and a person may therefore "want" and "like" something simultaneously. In the I-D model, D-type curiosity (CFD) is posited to involve high "wanting" and high "liking", while I-type curiosity (CFI) is theorised to involve low "wanting" and high "liking" (Litman, 2005).

A useful analogy for the wanting/liking distinction as it relates to acquiring knowledge might be appetite for salted food. Salt can be desired because it is required for the body to function, and therefore a nutritional deficit of salt would result in a wanting-type hunger. However, salt can also be desired for its hedonic value (consistent with its presence in fast-food), and therefore eating salted food for pure enjoyment would correspond to a liking-type hunger. Similarly, a person may desire a piece of knowledge because she is bothered by not knowing it (i.e. "wanting" or D-type curiosity), or because she finds learning new things enjoyable (i.e. "liking" or I-type curiosity).

There also remains the theoretical question of how state and trait curiosity might interact to promote exploratory behaviour. To assess this, Litman, Hutchins, and Russon (2005) asked participants questions that they could answer with one of three responses: "I know"; that the answer was on the "tip of the tongue" (TOT); or "don't know". This approach was intended to induce different feelings-of-knowing (FOK; a form of metacognitive judgment), which could then be compared with types of curiosity. Although the authors did not expect "I know" judgments to correspond with major components of curiosity, TOT judgments were expected to correspond with D-type curiosity, and "don't know" judgments with I-type curiosity.

Using this approach, they reported evidence for a hypothetical "chain reaction" relationship between trait curiosity, state curiosity, and exploratory behavior using path modelling. For "don't know" judgments, I-type trait curiosity (but not D-type) had a significant path to state epistemic curiosity, which had a significant path to exploratory behaviour. For TOT knowledge judgments, the D-type (but not I-type) trait curiosity had a significant path to state curiosity. Additionally, in both models FOK intensity also had significant paths to state curiosity. From this evidence, the authors hypothesised that trait variables "directly exerted their influences on state variables, which in turn would have a direct effect on behaviour" (Litman, Hutchins, et al., 2005, p. 574). Furthermore, Litman (2009) used this study to elaborate a theoretical model of the relationship between curiosity and metacognition. Here, he suggested that TOT judgments are understood to be of high intensity (arousing D-type curiosity), "don't know" judgments are of moderate intensity (arousing I-type curiosity), and "I know" judgments are of low intensity (arousing only desire for performance feedback). Grounding curiosity in research on brain systems thus provides further evidence of the distinctions Berlyne observed in animal and human behaviour.

Moreover, theoretical advances for curiosity have been made in terms of its relationship with approaches to learning. Richards, Litman, and Roberts (2013) compared the I-D model of curiosity, and NFC (Cacioppo & Petty, 1982), with deep and surface approaches to learning in medical students. Their findings were generally consistent with intuitive expectations: curiosity variables correlated positively with deep approaches to learning, and negatively with surface approaches.

However, an unusual finding of this study was that NFC did not have a significant path to the "deep approach" to learning in either path model, unlike I-type and D-type curiosity. This finding may be explained by the relationship between these curiosity variables. NFC correlated strongly with I-type curiosity (r = .74) and D-type curiosity (r = .57), and its zero-order correlations with deep approach, deep motives, and deep strategies were all substantial (rs = .47, .40, and .46 respectively)—though slightly less than those between I-type and D-type measures and these "deep" variables. Therefore, the strong overlap between NFC and the I- and D-type curiosity may have suppressed the path from NFC to "deep" variables. However, the NFC scale has also been shown to measures "intellectual avoidance" (Ferguson, 1999), so its substantial negative correlation with surface approaches to learning might be explained by this factor.

Overall, Litman has made practical and theoretical contributions to research on curiosity, especially the concise and well-validated scales assessing the I-D model using an individual differences approach. This leaves one more researcher to survey before drawing these threads together.

Mussel

Patrick Mussel has taken the concept of EC, as expounded by Berlyne and Litman, and has moved it in significant new directions. In an early study in this domain, Mussel (2010) called attention to several similar measures that have appeared in distinct research contexts, including TIE (Goff & Ackerman, 1992), Need for Cognition (Cacioppo & Petty, 1982), and Openness to Ideas (Costa & McCrae, 1992b)—an observation made by other researchers (e.g. Woo, Harms, & Kuncel, 2007). Mussel (2010) reported strong correlations between all measures of curiosity, and an exploratory factor analysis that showed a single factor explaining 67% of the variance across the six curiosity scale totals, suggesting a lack of discriminant validity between these scales. On this basis, Mussel (2010) suggested the need for future research to integrate findings from across these measures.

Mussel (2013a) subsequently proposed a framework called "Intellect" to integrate these measures, along with a corresponding scale. This framework proposes that personality variables relating to intellectual operations can be located along two dimensions, labelled *Process* and *Operation*. The first dimension Process refers to the motivational aspect of the framework, and is subdivided into two components: *Seek* and *Conquer*. Seek refers to the desire to search for new intellectual challenges, while

Conquer refers to the desire to master existing domains of knowledge. As Mussel observed, “The differentiation between Seek and Conquer is best understood from a process perspective as situational demands change in the course of an action” (2013a, p. 887). Notably, these processes have appeared in several previous approaches to organising curiosity variables, and correspond closely with *Interest* and *Deprivation* components of EC, respectively (Litman, 2008).

The second dimension Operation refers to specific activities undertaken in the course of an intellectual endeavour, and is subdivided into three components: *Think*, *Learn*, and *Create*. Mussel derived the components of this dimension from theories of intelligence (Carroll, 1993; Cattell, 1987), and noted that Think corresponds with fluid intelligence, Learn corresponds with crystallised intelligence, and Create corresponds with creativity. The meanings of these labels are intuitive: those who score high on Think spend time making logical deductions, and considering complex issues; those who score high on Learn spend time seeking knowledge and understanding; and those who score high on Create spend time “developing new ideas, concepts, strategies, and products” (Mussel, 2013a, p. 887). Further, combining the two dimensions produces six distinct facets that are proposed to span the conceptual space of Intellect: Seek Think, Seek Learn, Seek Create, and Conquer Think, Conquer Learn, Conquer Create (Mussel, 2013a, Figure 3).

Mussel (2013a) assessed predictions of the Intellect framework, principally in two ways. First, he assessed whether the scales identified previously (TIE, NFC, OI) could be integrated within this framework. He reported that they corresponded approximately with the relevant Intellect facets; for instance, both TIE and NFC aligned closely with the Seek Think facet. Second, the facets of Intellect were related to relevant outcomes, such as mathematics and English achievements, and the intention to work in a creative occupation, and the relative strengths of these correlations were generally as the model would predict. Overall, therefore, the Intellect framework (and its corresponding scale) has support as an effort to organise personality variables relating to intellectual activity. However, the reading dimension captured by the TIE scale showed substantial deviations from normality, and reading habits were therefore excluded from the Intellect framework. Thus, the question of whether reading habits should be integrated within the Intellect framework remains unanswered.

For our purposes, the most significant development in Mussel's approach has been his explicit attempt to align the components of Intellect with current thinking in intelligence theory. Although personality traits have often been defined based on their discriminant validity from intelligence variables, those within the Openness/Intellect domain are a clear exception. Mussel's approach acknowledges the close connection between these domains, and integrates them more thoroughly than previous attempts—an endeavour that Cattell probably would have commended.

2.5 Conclusion

As we have seen, an important shift in curiosity research has taken place over time, moving from a reliance on state to trait measures. Although many of the concepts have remained, the approach to measuring them has changed substantially. Because of this change, most recent attempts to measure curiosity have treated it as an individual difference variable (e.g. von Stumm, Hell, et al., 2011).

It is certainly legitimate to measure curiosity as a personality characteristic. However, we must ask whether something has been lost in this transition. As the survey in the *precursors to the trait approach* section made clear, the relationship between state and trait personality was not entirely clear, with conflicting evidence about how closely they related. Moreover, Litman's theoretical account treats them as distinct variables in a causal chain, suggesting that they both play necessary but unique roles in influencing exploratory behaviour.

There are other reasons to think that the state approach to researching personality is worth re-invigorating. For instance, as we saw in the previous chapter, the best measure of intelligence in infancy is preference for novelty, which looks remarkably like a precursor to intellectual curiosity, but also like general intelligence as indexed by IQ. This suggests that curiosity and intelligence are very closely related in the developmental period; is it likely that they simply part ways thereafter? Although measures of intelligence in adulthood often show only a modest association with curiosity, these measures of curiosity are usually trait-based and self-report. Far less research assessing the relationship between state curiosity and intelligence appears to have been conducted. Relying almost exclusively on self-report personality measures may have obscured the strength of this relationship.

For instance, Poropat (2014) provided evidence that self-report approaches to measuring personality variables attenuate the strength of their relationships with measures of academic achievement. He compared self- and other-rated FFM personality as predictors of achievement, and reported substantially stronger predictive validity for other reported measures for each FFM variable. This evidence suggests that self-report measures do not fully capture the potential of trait approaches to personality, and that these measures should be augmented with other-reported assessments. In the same vein, it is highly likely that state approaches to curiosity could also improve predictive validity, if only because they should correspond more closely with actual behaviours. As Langevin (1971) observed, "Personality measures of curiosity, like most personality measures, have been introspective reports of behavior rather than operational measures of observed behavior" (p. 362).

Clearly, in recent years curiosity research has shifted largely to the realm of trait-based approaches. While such personality scales are valid, useful, and easy to administer, the possibility remains that they are still limited proxies for the behaviours they intend to assess. Moreover, because of the unknowns that remain for measuring curiosity as a state, it may be time for research in this domain to swing back, and develop state measures of curiosity.

3 Investment Traits and Academic Performance

3.1 Introduction

As Chapter 1 indicated, a central feature of the investment theories of Cattell and Ackerman is that investment traits are argued to influence where and how people apply their intellectual abilities. In this regard, the domain of AP recently has been a focus of attention for the potential influence of investment traits IC and confidence. This final introductory chapter aims to assess the importance of these investment traits for predicting AP. Although these traits demonstrate predictive validity for AP, both share some degree of overlap with cognitive ability and aspects of FFM personality—variables that are also known to predict AP. Therefore, the predictive validity of intelligence and other personality measures for AP will first be evaluated, before the distinct contributions of IC and confidence are assessed in terms of their incremental validity. This chapter is presented under three main headings: *Intelligence and Academic Performance*, *Personality and Academic Performance*, and *Confidence and Academic Performance*.

3.2 Intelligence and Academic Performance

In general terms, the best predictor of AP is intelligence, as operationalised by IQ and similar tests (Neisser et al., 1996). This is to be expected, because measures of cognitive ability were developed in terms of AP: Spearman (1904a) used school grades to demonstrate the existence of *g*, and Binet developed his intelligence test to identify children who would struggle with the school curriculum (Nicolas, Andrieu, Croizet, Sanitioso, & Burman, 2013).

However, although this relationship is generally strong, evidence from a plethora of individual studies has indicated that strength of correlation varies substantially. Probably the strongest correlation has been reported by Deary, Strand, Smith, and Fernandes (2007). Using a population of more than 70,000 English school children, they obtained a correlation between latent variables of intelligence (Spearman's *g*) at age 11 and AP at age 16 of $r = .81$—supporting strongly Spearman's (1904a) intuition that these two constructs would associate close to unity (Deary et al., 2007). Other studies have reported substantial but lower correlations. For instance, Laidra, Pullmann, and Allik (2007) reported a cross-sectional study of intelligence, FFM personality and AP using Estonian school children from grade 2 to grade 12. Here, intelligence was the most powerful predictor in every grade, with correlations ranging from $r = .32$ to .54, with a median of .48.

Importantly, both studies listed above assessed primary or secondary cohorts, but the predictive power of cognitive ability has often been substantially reduced within tertiary cohorts. For instance, Chamorro-Premuzic, Furnham, and Ackerman (2006) reported a correlation of $r = .31$ ($p < .01$) between intelligence and exam performance in undergraduate psychology students, and Furnham, Chamorro-Premuzic, and McDougall (2003) found no significant relationship ($r = .07$, $p > .05$) between these variables in a very similar cohort. Smaller correlations have usually been explained by restriction of range for intelligence (Ackerman & Heggestad, 1997): because tertiary students are usually selected based on prior academic performance, the predictive power of intelligence in tertiary samples is curtailed, sometimes drastically

Moreover, the impact of range restriction has also been demonstrated by meta-analyses that have assessed this relationship at different levels of education. Roth et al. (2015) assessed this relationship for students in primary, middle, and high schools, with correlations of ρ = .45 (primary), .54 (middle), and .58 (high)—and with an overall association of ρ = .54 (all corrected for measurement error and range restriction). In this study, the trend was for the predictive power of cognitive ability to increase through the years of schooling. However, Poropat (2009) assessed this relationship for primary, secondary, and tertiary cohorts, and obtained meta-analytic correlations of ρ = .58, .24, and .23 respectively (corrected for measurement error but not range restriction), suggesting that the predictive power of cognitive ability drops substantially between primary and both secondary and tertiary education. Moreover, Richardson, Abraham, and Bond (2012) assessed a very large number of different constructs as predictors of university GPA, and reported the correlation ρ = .21 (corrected for measurement error but not for range restriction) between intelligence and AP. Furthermore, Kuncel, Hezlett, and Ones (2004) assessed the relationship between cognitive ability and grade point average (GPA) in graduate school (where students take masters or doctoral degrees), and reported an association of ρ = .39 (corrected for measurement error and range restriction). Therefore, although the evidence from meta-analyses is not entirely consistent with expectations, the predictive power of cognitive ability appears to diminish—but not disappear—between unselected (primary and secondary) and selected cohorts (tertiary), probably because of restriction of range.

Finally, although verbal (Gc) and non-verbal (Gf) abilities are relatively distinct from each other and from general ability (*g*), all three consistently correlate with AP.

Roth et al. (2015) reported the following fully-corrected estimates between AP measured across all measures of education and these abilities: ρ = .53 (verbal), .44 (non-verbal), and .60 (mixed measure/*g*). Once again, although individual studies will demonstrate variability in these associations, all three approaches to measuring intelligence are powerful predictors of AP.

Taking these results together, the predictive power of intelligence for AP appears to vary substantially, because the probable values for this correlation range from as high as about .8 to as low as about .2 depending on the population. Nonetheless, if the midpoint of approximately .5 is taken as a reasonable estimate, then intelligence accounts for about 25% of the variance in AP. Clearly, this estimate leaves most of the variance in AP unexplained. Several variables have been researched as having potential to bridge this gap, especially those in the domain of personality. These will be addressed next.

3.3 Personality and Academic Performance

Introduction

Much like the development of intelligence theory, the history of personality research has consisted of several models that have been proposed and then contested among researchers. In addition to debates concerning how best to measure such constructs, a major difference between models has been the number of personality factors that are argued to account for individual differences in behaviour. Although the contents of these proposals are not mutually exclusive—some are hierarchical and accommodate several levels of explanation—prominent models that have been proposed involve a single factor (van der Linden, te Nijenhuis, & Bakker, 2010), two (Digman, 1997), three (Eysenck, 1978), five (Costa & McCrae, 1992a), six (Ashton, Lee,

& Son, 2000), 10 (DeYoung, Quilty, & Peterson, 2007), and 16 factors (Cattell, Eber, & Tatsuoka, 1970). Many other less prominent models could be added to this list.

Structure of the Five-Factor Model

Factors. However, since the early 1990s, the most dominant framework for assessing personality has been the five-factor model (FFM), also known as the Big 5 (John, Naumann, & Soto, 2008). The proposed factors are Openness to Experience (OE), Conscientiousness, Extraversion, Agreeableness, and Neuroticism (Costa & McCrae, 1992a), and are sometimes remembered through the acronym OCEAN. But although this framework is dominant, it does not command universal assent. In addition to the issue of the number of factors, researchers have contested whether the FFM is truly universal (Gurven, von Rueden, Massenkoff, Kaplan, & Lero Vie, 2013), and have questioned the theoretical approaches used to arrive at the five factors (Block, 1995; Paunonen & Jackson, 2000). However, because it remains the most common taxonomy for personality, it possesses the most extensive evidence base to assess the question of personality associations with AP.

Facets. Although there are indeed several measures of the five factors, the most well-known are the NEO-PI-R, and its briefer version the NEO-FFI (Costa & McCrae, 1992b), which some consider to be the gold standard measures. The NEO-PI-R is a hierarchical scale that measures the five broad factors, and beneath each factor are six facets—narrow factors that assess more specific tendencies. This allows personality to be assessed at the factor and facet levels when this full scale is administered, and research indicates that the facets sometimes predict more variance than do the broad factors (see below). It is not necessary to list each of the 30 factors here; those of special interest will be introduced as required. But it should be noted that, similar to the debates concerning the FFM model at the factor level, other researchers would dispute the specific factors identified by Costa and McCrae (1992b) that inform the NEO-PI-R.

The Openness / Intellect domain. One such debate concerns the Openness / Intellect domain, which has received attention for being factorially complex, as is suggested by its alternative labels Openness, Culture, and Intellect (Goldberg, 1992). Within the NEO-PI-R, OE comprises the six facets Fantasy (O1), Aesthetics (O2), Feelings (O3), Actions (O4), Ideas (O5), and Values (O6), that are proposed to load on the higher-order OE factor. However, some research has indicated evidence for a tier in the hierarchy *between* factors and facets. DeYoung et al. (2007) argued that each of the five factors could be subdivided meaningfully into two sub-factors; in the case of this domain, they distinguished between Openness (to Experience) from Intellect, and used results from factor analysis to support their position. When considering the implications of this for the proposed structure of personality that underlies the NEO-PI-R, this rearrangement would in effect promote the facet Openness to Ideas, demote the factor Openness to Experience, and overarch them both by a higher-order factor whose contents are difficult to capture in a single term—hence the compound label "Openness/Intellect".[4]

The proposed Openness/Intellect distinction was then assessed by DeYoung, Shamosh, Green, Braver, and Gray (2009) using fMRI, who hypothesised that brain activity when subjects completed a difficult working memory task related to Intellect

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[4] For the other four FFM factors, DeYoung et al. (2007) provided sub-domain names that were different from the factor name (e.g. Extraversion comprises the sub-domains Enthusiasm and Assertiveness). But for Openness/Intellect, the sub-domains are simply Openness and Intellect.

but not Openness. Because the facets Ideas and Values demonstrated patterns of neural activity that, although not identical, were distinct from the patterns of the other four facets, the authors concluded that their proposed distinction between Openness and Intellect was supported by this study. Moreover, DeYoung et al. (2010) assessed the relationship between FFM traits and volume in brain regions where these traits were expected to have a biological basis. They found evidence for this for each FFM variable except for Openness/Intellect, thus adding to the growing body of evidence for biological underpinnings of personality variables.

Measures of intellectual curiosity. At this point, the research surveyed in this chapter converges with the research covered earlier, because the Intellect sub-domain overlaps explicitly with several measures introduced earlier. Chapter 1 introduced TIE in the context of Ackerman's PPIK theory of intelligence, where this dimension was distinguished from Openness to Experience in the FFM (Ackerman & Goff, 1994; Rocklin, 1994), and where Ackerman (1996) theorised that both dimensions would be important for the investment process. Moreover, Chapter 2 introduced Epistemic Curiosity—first from Berlyne's (1954) state perspective, and then from Litman's (2005) trait perspective—and noted that EC has been distinguished from Perceptual Curiosity, which appears to overlap very substantially with OE. Therefore, in each account of these avenues of research dimensions corresponding to Openness and Intellect have appeared. If the lexical hypothesis is legitimate for personality theory—that important personality traits would be expressed in language (Allport & Odbert, 1936)—then the distinction between Openness and Intellect has notable evidence in this regard. Considering the similarity between these measures, and despite their distinct origins, several researchers have suggested that these measures

TIE, EC, and OI assess the same broad construct that could be termed "intellectual curiosity" (Mussel, 2010, 2013a; von Stumm, Hell, et al., 2011; Woo et al., 2007).

Need for Cognition. Although it has not yet been covered in any detail, the construct Need for Cognition (NFC) belongs on this list, and has a two-part history. In its early history, Cohen, Stotland, and Wolfe (1955) defined NFC in the context of the process of making sense of the experiential world: "Need for cognition can be defined as a need to structure relevant situations in meaningful, integrated ways. It is a need to understand and make reasonable the experiential world" (Cohen et al., 1955, p. 291). In this sense, higher NFC would probably be required for those with higher Openness to Experience, because they would have more experiences to make sense of. Interestingly, the authors also note that the "assumption of such a need also implies that feelings of tension and deprivation arise from its frustration" (Cohen et al., 1955, p. 291). This aspect of the original definition of NFC parallels to some degree D-type curiosity within EC research—cognition that is prompted by feelings of discomfort. However, NFC research along the lines of this early definition was short-lived, possibly because the authors did not produce a scale to measure this tendency (Cacioppo & Petty, 1982)

In its later history, Cacioppo and Petty (1982) borrowed the term but redefined it as "the tendency for an individual to engage in and enjoy thinking" (p. 116). This positive redefinition clearly made NFC much more like other prominent measures of IC. Cacioppo and Petty (1982) developed a 34-item scale to measure this tendency, and Cacioppo, Petty, and Morris (1983) later condensed this to 18-items (Cacioppo, Petty, & Kao, 1984). Under its new definition, a very extensive program of research for NFC has ensued, including assessing its relevance for evaluating the strength of arguments

(Cacioppo et al., 1983), and its relationship with AP, gender roles, intelligence, and problem solving behaviour (Cacioppo, Petty, Feinstein, & Jarvis, 1996). Considering potential problems associated with some of its negatively-worded items (Bors, Vigneau, & Lalande, 2006), Furnham and Thorne (2013) produced positively-worded version of the 18- and 34-item scales that correlated very strongly with the originals. Research using NFC scales continues to the present day, and includes approaches that do not rely exclusively on self-report (Fleischhauer, Strobel, Enge, & Strobel, 2013; Fleischhauer, Strobel, & Strobel, 2015).

As noted in Chapter 1, several researchers have called attention to the very substantial overlap between these various constructs. In this respect, the following assessment seems appropriate:

> That is, measures of intellectual investment and curiosity have matching conceptual roots, including semantically identical items, and share criteria validity for academic performance and intelligence; therefore, they appear to assess the same trait dimension, and corresponding scales might be interchangeably used. (von Stumm, Hell, et al., 2011, p. 577)

Although these scales appear to be importantly different in several respects—including the measurement of reading habits by TIE, and the measurement of D-type curiosity by EC—they relate consistently enough to have been integrated within Mussel's Intellect framework (Mussel, 2013a). When taken together, this evidence indicates that the Openness/Intellect distinction is meaningful, and that both warrant investigation in the context of investment broadly, and AP specifically.

Personality and Intelligence Associations

Because intelligence is a powerful predictor of AP, and because it cannot be assumed that intelligence is entirely separate from some aspects of personality, it is first necessary to assess the overlap between personality variables and intelligence before considering personality variables as predictors of AP. In theory, correlations between measures of intelligence and personality should be near zero, but in practice this is often not the case (von Stumm, Chamorro-Premuzic, & Ackerman, 2011). This overview will consider relationship between cognitive ability and the FFM traits broadly, with a more detailed assessment of its overlap with the Openness/Intellect domain, starting with those FFM traits that show the least overlap.

Factors. Within the FFM, Agreeableness shows no consistent significant correlation with intelligence (Chamorro-Premuzic & Furnham, 2008; Moutafi, Furnham, & Crump, 2006). Although Extraversion and Neuroticism sometimes correlate substantially with cognitive ability, these correlations may reflect the nature of intelligence testing rather than intelligence *per se*. The direction of the association between Extraversion and intelligence depends on the nature of the test: extraverts tend to perform better on timed tests, and introverts on tests requiring understanding and thoughtfulness (Moutafi et al., 2006). The explanation may lie in resting cortisol levels, which are higher for introverts (Moutafi et al., 2006). And although Neuroticism sometimes correlates negatively with intelligence, this may be explained by neurotic individuals being more prone to test anxiety, which increases worry and hampers intelligence test scores (Moutafi et al., 2006). Therefore, it appears that Agreeableness, Extraversion, and Neuroticism are broadly independent of cognitive ability once their effects on performance in test-taking situations are considered.

Conscientiousness has proved a more difficult trait to assess in its relationship with ability. It sometimes demonstrates a small negative association with intelligence (Judge, Jackson, Shaw, Scott, & Rich, 2007; Moutafi et al., 2006), which has been explained by the so-called intelligence compensation hypothesis. This proposes that Conscientiousness is an adaptive trait: individuals with higher intelligence learn to rely on their intelligence for success in life, while those with lower intelligence must work harder to succeed, and become more conscientious in the process (Chamorro-Premuzic & Furnham, 2005; Moutafi, Furnham, & Paltiel, 2004). However, recent evidence has suggested that the weak negative correlations between these variables may have been a result of sampling non-representative cohorts, and that unselected cohorts demonstrate negligible or even weak positive associations between cognitive ability and Conscientiousness (Murray, Johnson, McGue, & Iacono, 2014). If this is the case, the intelligence compensation hypothesis may not apply at the population level. Despite this dispute, most research indicates that the correlations between these constructs are small—even if sometimes significant—and therefore they can be treated as relatively independent constructs for most purposes (Ackerman & Heggestad, 1997; Poropat, 2009; von Stumm, Hell, et al., 2011).

Openness/Intellect. If the aim is to identify personality factors that correlate consistently and substantially with intelligence, then only the Openness/Intellect domain qualifies. Occasionally, individual studies have reported no significant relationship between the two (DeYoung et al., 2009), but meta-analyses have tended to report substantial small-to-moderate correlations between cognitive ability and OE, including ρ = .15 (Poropat, 2009), .22 (Judge et al., 2007), and .33 (Ackerman & Heggestad, 1997). Importantly, when Gf and Gc are measured as distinct constructs, OE tends to show non-significant (Chamorro-Premuzic & Furnham, 2008; Goff & Ackerman, 1992) or weak ($r = .09$, $p < .001$) correlations with Gf (Moutafi et al., 2006)—although moderate correlations (up to $r = .18$, $p < .001$) have been reported (Ashton, Lee, Vernon, & Jang, 2000). However, correlations with Gc have been more consistent and substantial, including $r = .22$ (Goff & Ackerman, 1992), $\rho = .30$ (Ackerman & Heggestad, 1997), and $r = .37$ (Ashton, Lee, Vernon, et al., 2000). Therefore, the general trend has been that where OE correlates substantially with general ability, this owes more to its relationship with Gc than with Gf.

Moreover, several studies have reported associations between general intelligence, Gf, Gc, and the facets of OE. Thus, DeYoung et al. (2009) reported correlations of these facets with general ability but found significant relationships only for Ideas ($r = .27$) and Values ($r = .33$; $p < .01$). Moutafi et al. (2006) associated OE facets with Gf, and reported significant correlations with Actions ($r = .07$) and Ideas ($r = .20$; $p < .001$). And von Stumm and Ackerman (2013) reported meta-analytic associations between OE facets and Gc, where all facets except Actions correlated significantly with Gc. Using a random effects model, the authors reported modest associations between Gc and Fantasy ($\rho = .17$), Aesthetics (.25), and Feelings (.25), while strong associations were reported for Ideas (.52) and Values (.53; all $p < .05$). Overall, the facets of OE vary substantially in their overlap with intelligence, but Ideas and Values appear to overlap the most.

Other measures of intellectual curiosity. Finally, having assessed those constructs that relate predominantly with the Openness subdomain, the other measures that relate to the Intellect dimension will now be assessed in terms of their overlap with cognitive ability. Openness to Ideas was addressed in the previous paragraph, leaving TIE, NFC, and EC, and Mussel's Intellect scale to be considered.

Typical Intellectual Engagement. Several individual studies have assessed the relationship between TIE and cognitive ability, including Schroeders, Schipolowski, and Böhme (2015) who reported a correlation of r = .20 (p not reported)[5] between TIE and Gf. Moreover, Mussel (2010) reported correlations between TIE and both Gf (r = .11, p > .05) and Gc (r = .20, p < .05), and Powell and Nettelbeck (2014a) obtained a correlation of r = .33 (p < .01) between TIE and Gf. Furthermore, von Stumm and Furnham (2012) reported the correlation r = .12 (p < .01) between TIE and general cognitive ability. Two meta-analyses have also assessed this relationship. Ackerman and Heggestad (1997) reported a correlation of r = .22 (p < .05) between TIE and g, r = .07 (p > .05) between TIE and Gf, and r = .35 (p < .05) between TIE and Gc. Finally, von Stumm and Ackerman (2013) reported a meta-analytic correlation of ρ = .38 (p < .05) between TIE and Gc. Therefore, TIE appears to correlate substantially with g, possibly because it overlaps more extensively with Gc than with Gf.

Need for Cognition. The relationship between NFC and cognitive ability has been assessed in several studies. Mussel reported non-significant correlations between NFC and both Gf (r = .16, p > .05) and Gc (r = .07, p > .05), whereas Powell and Nettelbeck (2014a) obtained a correlation of r = .36 (p < .01) between NFC and Gf. Bors et al. (2006) reported the non-significant correlation r = .07 (p >.05) between NFC and Gf, and a significant correlation r = .23 (p < .05) between NFC and a measure of Gc. However, probably the strongest result from a single study of the relationship between

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[5] The reported sample size n = 4032 suggests this correlation would be highly significant.

NFC and cognitive abilities is that reported by Hill et al. (2013), who used WAIS-III scores to estimate these associations. They reported a zero-order correlation of $r = .38$ ($p < .001$) between NFC and g, and used structural equation modelling to provide the estimates $\beta = .40$ ($p < .001$) between NFC and Gf ($p < .001$), and $\beta = .32$ ($p < .001$) between NFC and Gc. Finally, using meta-analysis, von Stumm and Ackerman (2013) reported a meta-analytic correlation of $\rho = .27$ ($p < .05$) between NFC and Gc. Clearly these correlations are variable, but NFC appears to overlap substantially with all measures of cognitive ability—perhaps more so with Gf than with Gc, although this is not certain.

Epistemic Curiosity. There are fewer studies available to assess the relationship between cognitive ability and EC than there are for TIE and NFC. Powell and Nettelbeck (2014a) obtained a correlation of $r = .21$ ($p < .01$) between EC and Gf. Mussel (2010) assessed the relationship between diversive and specific EC with Gf and Gc, but found no significant correlations, although specific curiosity correlated weakly in the positive direction with Gc ($r = .19$, $p < .10$). Thus, the trend for these correlations appears to be positive, although no firm conclusions about this relationship can be obtained from this limited sample.

Mussel's Intellect scale. Finally, and probably because it is quite recent, little information is available about the relationship between Mussel's Intellect scale and cognitive ability. The validation study of Mussel (2013a) reported a correlation of $r = .20$ ($p < .01$) between Intellect and Gf, and .14 ($p < .01$) between Intellect and Gc. Therefore, it appears that Intellect overlaps with Gf and Gc, and perhaps slightly more with the former than with the latter.

Conclusion. These results of this review suggest that measures of Intellect correlate substantially with measures of intelligence, but also that these correlations are not consistent. NFC appears to overlap more substantially with Gf than with Gc, whereas TIE shows the opposite trend. There are very few associations available between cognitive ability and both EC and Intellect, but what is available indicates some overlap between these domains. Mussel (2010) suggested that the more substantial overlap between TIE and Gc may be attributed to its measurement of reading, which no other scale appears to measure. However, the differences apparent in these associations may also be due to different scale lengths (EC is 10 items, whereas TIE is 59 items), the limited numbers of studies, and differences across sample populations. Nonetheless, these domains overlap clearly, and therefore any study that seeks to measure the incremental validity of IC measures must first take account of cognitive ability—preferably by measuring both Gf and Gc.

Personality as a Predictor of Academic Performance

Predictive validity. There exists a large body of evidence addressing the predictive validity of FFM personality traits for AP (as noted by Briley, Domiteaux, & Tucker-Drob, 2014), which has been evaluated in several meta-analyses conducted in the last decade. Although most of these meta-analyses have analysed self-reported data using tertiary students, Poropat (2014) compared the predictive validity of other-reported FFM personality variables to self-reported data, using secondary and tertiary students. Here, Poropat's (2009) analysis, which addressed the predictive validity of FFM personality for AP across all academic levels (i.e. primary, secondary, and tertiary), will be surveyed first, followed by studies using tertiary students, and then followed by the study comparing other-reported with self-reported data. Moreover, rather than citing every correlation, only meta-analytic correlations above .10 (usually Pearson's *r* or Spearman's ρ) will be considered to be of practical significance (i.e. substantial), even though outcomes have been statistically significant in most cases because of the very large samples involved. Because of different methodologies in each study, the most fully-adjusted and corrected correlations in each study will be cited to permit comparison.

Factors. Poropat (2009) assessed FFM variables as predictors of AP across all levels of education. Here, Agreeableness predicted substantial variance in AP only in primary samples (ρ = .30). Conscientiousness did so when all levels of education were assessed together (.24), and for primary (.28), secondary (.21), and tertiary (.23) samples individually. Emotional stability (lower scores on Neuroticism) only predicted substantial variance in primary samples (.20), and the same was true for Extraversion (.18). The predictive validity of Openness differed substantially by academic level, although the relationship was significant overall (.12), for primary (.24) and for secondary students (rho = .12). However, Openness was not a substantial predictor for tertiary students. Overall, in this study Conscientiousness was the most substantial and reliable FFM predictor of AP, followed by Openness; whereas Agreeableness, Neuroticism, and Extraversion were substantial predictors only for primary student samples.

Four meta-analyses that assessed the relationships between FFM variables and AP only in tertiary students were identified (O'Connor & Paunonen, 2007; Richardson et al., 2012; Schuler, Hirn, Hell, & Trapmann, 2007; Vedel, 2014). Every study obtained a substantial relationship between Conscientiousness and AP, ranging from ρ = .23 (Richardson et al., 2012) to μ_ρ = .27 (Schuler et al., 2007). Openness to Experience associated $\mu = .13$ in Schuler et al. (2007), but the 90% credibility value crossed zero, indicating that this result cannot generalised. The other studies did not report substantial correlations between Openness to Experience and AP; and in no study did Extraversion, Agreeableness, or Neuroticism correlate substantially with AP in university students. Therefore, tertiary samples appear to show much the same pattern of association between FFM personality and AP as do general samples.

However, as noted above, all these studies relied on self-reported FFM personality. Poropat (2014) assessed whether self-reported personality measures underreport the true relationship between FFM personality and AP by comparing their predictive validity with other-reported FFM measures, using secondary and tertiary samples. Here, Conscientiousness was the most powerful predictor ($\rho = .38$), followed by Openness to Experience (.28), followed by Neuroticism (.18) and then Agreeableness (.10). Extraversion did not predict substantial variance in AP. Clearly the trend of these associations was the same as for the self-reported measures, although the correlations were substantially stronger.

This finding is enlightening, because potentially it demonstrates a source of substantial measurement error that has contributed to systematically underestimating the relationship between FFM and AP outcomes. If this is so, four of the five FFM variables may be substantially related to AP, when usually only Conscientiousness and (possibly) Openness to Experience have been thought to do so. Moreover, this raises the possibility that the combined predictive power of personality variables may exceed that of intelligence. Nonetheless, many studies—including those reported in this thesis—will continue to rely on self-report FFM measures, because they are easier to administer. And the results of meta-analyses on these studies have indicated that

Conscientiousness is a consistent and substantial predictor of AP, and that Openness to Experience provides a less consistent and more modest contribution to predicting AP.

Facets. In passing, it is worth noting that some researchers have reported that FFM personality variables measured at the facet level can potentially predict more variance in AP than can the broad factors. Paunonen and Ashton (2001) compared the relative efficacy of FFM traits and facets in predicting AP, and found that the narrow traits of need for achievement (a facet of Conscientiousness) and need for understanding (a facet of OE) predicted more variance in AP than their respective broad traits. In addition, Chamorro-Premuzic and Furnham (2003) found that although broad FFM traits accounted for about 15% of variance in AP in university exams, selected facets for Conscientiousness (achievement striving and self-discipline) and Extraversion (activity), when combined, accounted for nearly 30%. This raises the possibility that certain facets of FFM personality possess more predictive power for AP than do the broad factors. Moreover, research on the Openness to Ideas facet of OE in effect is an application of this point. However, Chamorro-Premuzic et al. (2006) noted the lack of a consistent pattern for facet-level associations with AP. Currently, whether assessing facet-level associations more closely will help to bridge the explanatory gap between AP and its predictors remains uncertain—except for OI within OE.

Measures of intellectual curiosity. Because the contents of the Openness/Intellect domain are factorially complex, and because this domain tends to predict AP, the relationship between measures of IC and AP will be assessed in more detail. In research to date, Typical Intellectual Engagement has shown the strongest relationship with AP. Although the meta-analysis by von Stumm, Hell, et al. (2011)

assessed this to be $\rho = .33$, ostensibly on the basis of four studies, this correlation was later reduced to .29 by von Stumm and Ackerman (2013) because two of the correlations in the earlier study were actually derived from the same participants. Moreover, Powell and Nettelbeck (2014a) reported a correlation of $r = .35$ between self-reported university entrance scores and TIE measured approximately six months later, and Schroeders et al. (2015) reported $r = .27$ between TIE and mathematics achievement in German secondary students. Finally, probably the strongest relationship between TIE and AP has been reported by Furnham, Monsen, and Ahmetoglu (2009), who obtained $r = .41$ when assessing total subject scores in British secondary students. Therefore, TIE and AP show substantial zero-order correlations of around $r = .3$ in several studies.

A meta-analysis of Need for Cognition as a predictor of AP by Richardson et al. (2012) estimated this relationship to be $\rho = .17$ in university students. This result was similar to that reported by von Stumm and Ackerman (2013) who estimated it to be $\rho = .22$ in what were almost exclusively tertiary samples. However, only recently have more studies appeared that have assessed the relationship between NFC and AP in primary and secondary students. Powell and Nettelbeck (2014a) reported a correlation of $r = .33$ between university entrance scores (i.e. grade 12 achievement) and NFC measured about six months later—very similar to $r = .35$ association between TIE and AP noted above. Further, Luong et al. (2017) assessed NFC–AP associations in $N = 4{,}279$ Finnish students, and reported latent correlations of $r = .09$ (grade 3), .27 (grade 6), and .31 (grade 9; all *p*s $< .01$). Finally, Preckel (2014) assessed NFC–AP associations in $N = 745$ German school students, and reported positive associations with mathematics achievement in grade 5 ($r = .16/.17$; scale means/factor scores, respectively) and grade 6 (.24/.23), whereas associations between grades for other subjects were "positive but mostly nonsignificant" (p. 69). Therefore, although the trend appears to put the NFC–AP association closer to .2 than to .3, the possibility remains that this variation is a consequence of the samples used, with stronger correlations appearing for unselected than selected samples.

Lastly, relationships between AP with EC, Intellect, and OI can be summarised briefly due to the more limited data available. Powell and Nettelbeck (2014a) reported $r = .20$ between AP and EC; Mussel (2013a) reported correlations between the Intellect scale and mathematics achievement of $r = .19$, and between Intellect and English achievement of $r = .10$ in a sample mostly comprised of German secondary students; and von Stumm and Ackerman (2013) reported $\rho = .08$ between OI and AP in their meta-analysis. Therefore, across all measures of IC, the trend appears to be for consistent, positive associations with AP—although the possibility exists that some predict AP more strongly than do others.

Incremental validity. Considering the predictive validity of both cognitive ability and personality measures for AP, the question remains about the distinct contribution of IC measures over and above these ability and personality traits. Because of the overlap demonstrated between these variables, it is not sufficient to show that IC has predictive validity; to be a useful predictor of AP, it must also demonstrate incremental validity. There are five studies that have assessed this issue: two studies that assessed secondary students, two that assessed tertiary students, and a meta-analysis that pooled results from both academic levels.

For secondary students, Furnham et al. (2009) assessed TIE, measures of cognitive ability, FFM personality, and approaches to learning as predictors of AP in a

British sample. The predictive power of TIE was assessed using two hierarchical regressions, each with a different order of entry. Unfortunately, the approach to these regressions makes it difficult to assess the incremental validity of TIE above cognitive ability and FFM personality, because in neither regression was TIE entered after both cognitive ability and FFM personality. In the first regression, TIE explained 2–3% incremental variance in AP (total scores across subjects) above cognitive ability, whereas in the second regression TIE (and measures of approaches to learning) explained 13–16% incremental variance in AP (total scores) above FFM personality measures. Therefore, had the incremental validity of TIE been assessed above cognitive ability and FFM personality, it would have been no more than 2–3%.

Moreover, Schroeders et al. (2015) assessed the contribution of TIE above background measures, Gf, and subject-specific interest in German secondary students. Using the outcome variables of mathematics and science grades, they reported very limited incremental validity for TIE above gender, migration, SES, Gf, and subject-specific interest; between 0.5% and 1.8% depending on the subject. However, they did not assess other personality measures at all, which probably would have reduced the extent of incremental validity further still.

Finally, in the validation study for the Intellect scale, Mussel (2013a) used a sample of mostly German high school students to assess the incremental validity of the three Intellect operations (Seek, Learn, Create) above measures of Gf and Gc for self-report high school grades for mathematics and English. For mathematics grades, Gf and Gc predicted 5.1% of variance (adjusted R^2, $p < .01$) at step 1, and adding the three Intellect operations at step 2 increased the explained variance by 3.7% to 8.8% (adjusted R^2 change $p < .01$). At step 3, adding six interaction terms between Intellect operations and both Gf and Gc did not increased the variance explained (adjusted R^2 change p = .70). For English grades, Gf and Gc predicted 1.3% of variance (adjusted R^2, p = .03) at step 1, and adding the three Intellect operations at step 2 increased the explained variance by 2.2% to 3.5% (adjusted R^2 change p = .01). At step 3, adding six interaction terms between Intellect operations and both Gf and Gc did not increased the variance explained (adjusted R^2 change p = .60). Therefore, in secondary samples TIE appears to have only modest incremental validity, and in some cases this is without removing the unique variance explained by FFM personality measures.

For tertiary students, Chamorro-Premuzic et al. (2006) used a psychology sample to assess the incremental validity of TIE above cognitive ability and FFM personality. They used several different measures of AP (including continuous assessment, essays, a final project, and exams), and obtained incremental validity in each case, ranging from 3–9% across methods. However, Powell and Nettelbeck (2014a) assessed the incremental validity of four different measures of IC—TIE, NFC, EC, and IPIP-Intellect (essentially Openness to Ideas in the NEO-PI-R)—in a sample of psychology students, controlling for Gf and Conscientiousness. Importantly, although this study used a tertiary sample, its outcome measure for AP was the achievement score awarded each student in final state-wide exams held at the conclusion of the final year of secondary education (year 12). Participants provided their own score. These scores were earned about six months earlier than the other measures, and probably therefore make the results of this study more comparable to those using secondary samples. Powell and Nettelbeck (2014a) reported that, of the four scales measuring IC, only TIE showed evidence of incremental validity (1.8% above Gf and Conscientiousness). Furthermore, a general factor of IC extracted from the four scales showed no evidence of incremental validity. Therefore, the evidence for incremental validity of measures of IC for AP in tertiary samples is mixed—although the difference between the outcome measure of AP in these studies should be noted.

Finally, von Stumm, Hell, et al. (2011) assessed whether IC (measured by TIE) made a distinct contribution in predicting AP above *g* and Conscientiousness with meta-analysis and structural equation modelling. Their meta-analysis used several studies—including Chamorro-Premuzic et al. (2006)—to calculate meta-analytic coefficients for the relationships between TIE and AP, *g*, and Conscientiousness, and borrowed coefficients from previous meta-analyses for the other correlations. They reported that the direct path from TIE to AP explained distinct variance in AP (beta = .20)—equivalent to the influence of Conscientiousness (beta = .20) but less than the influence of *g* (beta = .35). Therefore, the authors concluded that IC is the "third pillar" of AP alongside intelligence and Conscientiousness.

Conclusion

Overall, the evidence for the incremental validity of IC appears to be mixed. The two studies using secondary students showed only modest incremental validity. Moreover, if the study of Powell and Nettelbeck (2014a) is placed in this category (because it relied on high school scores used to gain entry to university), the evidence in tertiary samples relies entirely on a single study, which provides the only evidence for substantial incremental validity. If evidence for incremental validity can only be obtained in a cohort with substantially restricted range for intelligence, this might call into question the ability to generalise this to unselected cohorts. Moreover, although von Stumm, Hell, et al. (2011) concluded that IC is the "third pillar" of AP, only a very limited number of studies have assessed the incremental validity of IC measures.

Finally, although the approach to the meta-analysis of von Stumm, Hell, et al. (2011) assumed that the relationships between these variables within secondary and tertiary populations are interchangeable, this assumption requires closer examination to substantiate. Overall, the variable nature of the evidence available suggests that the incremental validity of IC for predicting academic outcomes remains an open question.

3.4 Confidence and Academic Performance

Having considered IC as an investment trait that predicts AP, this section will now turn to assessing confidence in this regard. This section will proceed under five headings: *Introduction to Confidence*; *Confidence and Intelligence Associations*; *Confidence and Personality Associations*; *Confidence, Metacognition, and Investment Theory*; and *Confidence and Academic Performance*.

Introduction to Confidence

Stankov, Kleitman, and Jackson (2015) have identified two distinct approaches to measuring confidence[6]. The first approach uses self-report, which assesses confidence through questionnaire items designed to tap into characteristics of confidence—in a similar manner to much personality assessment—and thus relies on a person's self-insight. The second approach is the so-called "online" methodology, which has been inspired by the work of Lichtenstein and Fischhoff (1977). Here, the question "How confident are you that your answer is correct?" follows each item in an assessment, scored on a scale of 0–100%, and responses are then averaged to measure

[6] As Stankov, Lee, Luo, and Hogan (2012) note, although "confidence" is synonymous with "self-confidence", the shorter designation is to be preferred given that the meaning of "confidence" is already self-referential.

overall confidence. The total scores can also be compared with actual test scores to calculate whether participants are under- or over-confident, given the difficulty of the test. The online approach has been shown to have excellent internal consistency and test-retest reliability (Stankov et al., 2015), to predict achievement across different countries and cultures (Morony, Kleitman, Lee, & Stankov, 2013), and to vary less substantially between countries than do assessments of cognitive ability (Stankov & Lee, 2014).

Moreover, it is noteworthy that only one study has assessed simultaneously both self-report and online measures of confidence—probably because these methods have been developed independently. Burns, Burns, and Ward (2016) assessed scores on two self-reported measures of confidence, online confidence scores attached to two measures of Gf, one measure of Gc, and measures of five-factor model (FFM) personality. Among other analyses, the authors reported a three-factor exploratory structural equation model for measures of confidence, Gf and Gc test accuracy scores, and FFM personality variables. Here, self-report confidence measures and Neuroticism defined the first factor, the four other FFM variables defined the second factor, and measures of online confidence and accuracy scores defined the third factor. The correlations between the three factors were weak (r = .05, .11, and .13) and non-significant. On this basis, the authors concluded that measures of self-report and online confidence are separate factors that cannot be used interchangeably, and that self-report confidence sits closer to personality measures (especially Emotional Stability, the obverse of Neuroticism), whereas online confidence sits closer to ability measures. Considering this evidence, and because the online approach has more substantial support for predicting academic performance, this section on confidence will be limited to addressing this construct.

Several studies have indicated that online confidence is a broad trait, because it appears when factor analysis is applied to measures of confidence which are attached to different kinds of assessment (reviewed below). Given this evidence, some researchers have suggested that confidence may be a general factor, analogous to the general factor of intelligence: “It appears that empirical evidence for a broad or perhaps general confidence factor is mounting” (Stankov et al., 2012, p. 757; Stankov et al., 2015).

Another pertinent question is the relationship between confidence and other apparently similar variables that assess self-belief. In particular, three measures of self-belief have been identified as being educationally relevant through a large-scale, international study reported by Lee (2009): self-efficacy, self-concept, and anxiety. *Self-efficacy* refers to a person’s ability to effect outcomes; an example item is, “I am sure I can do difficult work in my English class”. *Self-concept* refers to a person’s self-perception; an example item is, “In my mathematics class I understand even the most difficult work”. *Anxiety* refers to a person’s emotional and physiological reaction to performing work in specific domains; an example item is, “I often worry that it will be difficult for me in mathematics classes” (definitions and example items from Stankov et al., 2012, p. 749).

The principal difference between online confidence and these self-belief measures is their relative domain specificity. Although confidence measures are attached to individual test items, the overall confidence scores have the nature of a broad trait, predicting outcomes in different domains than those from which they were obtained. However, the efficacy of self-belief measures appears to be domain-specific; for instance, mathematics self-concept appears to be unrelated to performance in an English class (Stankov et al., 2015). Moreover, Stankov, Morony, and Lee (2014) reported that confidence captures much of the variance explained by these three measures of self-belief, suggesting that measuring confidence makes measuring self-belief unnecessary.

Nevertheless, the distinctness of confidence from self-belief measures has previously been demonstrated by Stankov and Crawford (1997), who assessed English and Maths self-concept measures in a sample of 271 (193 females) first-year university students. Because self-concept and confidence are both self-assessments of one's abilities, the researchers anticipated a modest overlap when these were assessing the same domain. They reported that confidence ratings for Gc correlated significantly with English self-concept (r = .32), and confidence ratings for Gf correlated significantly with Maths self-concept (r = .20), while confidence ratings for non-relevant task performance did not significantly predict English or Maths self-concept (i.e. Gv and Gf for English; Gv and Gc for Maths). These findings were consistent with expectations, and indicated that, while confidence measures overlap modestly with self-concept measures in the same domain, they are also distinct constructs. This leads us to an assessment of other constructs to which confidence has been compared.

Confidence and Intelligence Associations

In theory confidence ratings could be attached to any test, but in practice they are usually yoked to tests of cognitive ability. Several studies have indicated that confidence judgments assessed across tests of both fluid and crystallised abilities load onto the same broad factor. Stankov and Crawford (1996) assessed measures of broad visualization (Gv), Gf, and Gc, and found that confidence scores attached to these measures correlated substantially with each other (Gv–Gf $r = .47$, Gv–Gc $r = .39$, Gf–Gc $r = .52$), indicating a distinct factor. Moreover, they reported that the correlations of confidence with accuracy (i.e. number of items correct) were $r = .21$ (Gv), .51 (Gf), and .63 (Gc) respectively, suggesting that confidence scores predict Gf and Gc abilities more than they do Gv ability.

Stankov (2000) compared confidence with self-evaluation (i.e. where participants estimated how many test items they solved correctly upon completing a test) on five tests of Gf, and demonstrated a distinct confidence factor using exploratory and confirmatory factor analyses, plus weaker evidence for a distinct self-evaluation factor. Measures of confidence predicted substantial variance in Gf test scores (*r*s = .40—.68), confirming that confidence overlaps substantially with intelligence, but is also distinct from it as indicated by factor analysis.

Kleitman and Stankov (2007) assessed confidence in relation to performance on a battery of different cognitive tests. Using confirmatory factor analysis, they reported that a solution with five factors obtained the best fit, with distinct factors corresponding to Gf, Gc, speed, confidence, and metacognition, and that the confidence factor correlated substantially with Gf ($r = .34$), Gc ($r = .20$), and metacognition ($r = .41$)—indicating that it is distinct from, but related to, both intelligence and metacognition. Moreover, Stankov and Lee (2008) attached confidence ratings to a measure of verbal comprehension (including listening and reading components), and reported an exploratory factor analysis in which verbal ability and confidence measures loaded distinct factors.

However, a distinct confidence factor has also been obtained using batteries of tests including both cognitive and perceptual tasks. Pallier et al. (2002) demonstrated that confidence ratings on perceptual tasks (including discriminating line length, pitch, and smell) loaded onto the same factor as confidence ratings attached to cognitive tests. Taken together, these studies indicate that confidence overlaps substantially with cognitive ability, but is more than cognitive ability, as is shown by its overlap with sensory modalities.

Confidence and Personality Associations

A small number of studies have assessed the relationship between confidence and factors of personality. Pallier et al. (2002) compared confidence ratings with Extraversion at the factor and facet levels (using the NEO PI-R), and found no significant correlation between Extraversion broadly, but a significant correlation with its facet Activity (r = .26, p < .01), as well as a correlation of r = .35 (p < .01) between confidence and a measure of proactiveness. Furthermore, Stankov and Lee (2008) compared confidence scores with each FFM factor, and found substantial overlap with Openness to Experience (r = .33) and Agreeableness (r = .23), with an average correlation across the five factors of r = .18. They noted that FFM variables appear to have the same relationship with confidence as they do with cognitive abilities, which suggests that the overlap between confidence and Openness to Experience may be due to the shared variance of each with intelligence.

Lastly, Burns et al. (2016) assessed the relationship between FFM variables and online confidence samples. In their sample of younger adults, online confidence attached to two measures of Gf correlated significantly with Neuroticism (r = -.28 and -.27) as did confidence scores attached to the measure of Gc (r = -.22), but no other correlation between online confidence and FFM variables was significant. In the sample of older adults, significant associations between online confidence and each FFM variable were reported. However, these were generally inconsistent between the two measures of Gf, and this instability may have been due to the smaller sample of older adults (n = 91) compared with the sample of younger adults (n = 144), making the true extent of this overlap difficult to ascertain. Although this limited number of studies does not allow a firm estimate of the degree of overlap between confidence and each FFM variable, they suggest that substantial overlap between these domains may exist.

Confidence, Metacognition, and Investment Theory

In addition to the above empirical findings, confidence has been discussed in connection with Cattell and Ackerman's investment theories. Stankov (1999) described confidence—along with other variables including emotional intelligence—as residing on the so-called "no man's land" between intelligence and personality. He surveyed evidence which indicated that cognitive abilities became less powerful predictors of life outcomes as people moved into occupational pursuits, but that non-cognitive variables (including personality) become increasingly important at the same time—with special reference to those abilities that straddle the borderline of ability and personality.

Stankov (1999) assessed the question of whether confidence was closer to cognitive ability, personality, or metacognition. He reviewed the evidence available, noting that confidence showed only modest or negligible correlations with intelligence and personality, and that it appeared to overlap most substantially with aspects of metacognition. More specifically, he argued that confidence appeared to assess the dimension of self-monitoring: “an individual’s propensity to appraise (or judge) the degree of accuracy of one’s own performance in the course of working through the items of a cognitive test” (Stankov, 1999, p. 324).

When seen in this light, confidence appears to fit Cattell’s definition of an “investment trait”, in its capacity as a motivational variable. Those with higher levels of confidence may be quicker to act than those with less confidence, who may be less decisive due to excessive rumination. When this process is considered in terms of acquiring knowledge, those with greater degrees of confidence may engage new intellectual pursuits more readily, and therefore be quicker to initiate the interaction between ability, knowledge, and interests as described by Ackerman’s PPIK theory. Indeed, viewed from a broad perspective, the role of confidence

> may be to provide a person with the information relevant for an evaluation of his or her strengths and weaknesses and to act as a motivational force that is important for ensuring maximal cognitive effort in that person’s areas of strength. The level of self-confidence may be related to feelings of self-esteem and contribute to one’s realistic outlook on aspects of achievement and on life in general. (Stankov, 1999, p. 325)

Moreover, in a more recent review, Stankov (2013) applied the above process to investment theory specifically: “It seems reasonable to assume that self-beliefs and confidence in particular are the most potent forces that lead to the development of crystallized intelligence as postulated by the investment part of the theory of fluid and crystallized intelligence” (p. 731). This view was re-affirmed in a recent analysis of the relationship between measures of self-belief (including confidence) as they relate to intelligence and mathematics achievement (Stankov & Lee, 2017). Although recent discussions highlight variables such as intellectual curiosity as potentially important in the investment process (e.g. von Stumm, Hell, et al., 2011), confidence may also have an important part to play.

Confidence and Academic Performance

In a selective review of non-cognitive predictors of academic performance, Stankov (2013) reported that confidence was the only measure consistently to correlate stronger than $r = .45$ with academic outcomes. However, a more stringent assessment is to assess the incremental validity of confidence beyond variance explained by other variables, including domain-specific ability, which at least two studies have assessed.

For verbal ability, Stankov and Lee (2008) reported associations between confidence and self-reported high school GPA and SAT scores, and for the Test of English as a Foreign Language (TOEFL)—a measure of verbal ability which assesses reading, listening, writing, and speaking skills in English. Although the measure of verbal comprehension showed predictive validity for GPA and SAT scores ($R^2 = .079$ and .307 respectively), adding confidence ratings did not improve prediction, which the authors speculated may have been due to using self-report measures. For TOEFL reading and listening scores (summed), the total TOEFL scores predicted $R^2 = .875$, and adding confidence scores to this raised explained variance to $R^2 = .877$ (R^2 change $p < .05$).[7] However, although significant, the authors conceded that "the value of obtained incremental validity is minimal" (Stankov & Lee, 2008, p. 974).

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[7] The sample size in this comparison appears to have been $n = 824$. Although the difference of .2% between these figures seems unlikely to have been statistically significant, the authors did not provide sufficient details about the regression model to check this. But regardless of whether these numbers were significantly different, they are not practically different.

For maths ability, Stankov et al. (2012) compared confidence with other self-belief constructs as predictors of maths grades in a sample of 15-year-old Singaporean students. This study involved assessing measures of maths accuracy (using an achievement test), maths confidence (attached to the achievement test), maths self-efficacy, maths self-concept, and then compared these measures to maths class achievement three months later. Both maths confidence and maths anxiety were significant ($p < .01$) zero-order predictors of maths school grades ($r = .55$ and -.39 respectively), and both remained significant predictors after maths accuracy had been partialled out ($r = .27$ and -.23), while maths self-efficacy and maths self-concept were not significant predictors in either respect. Therefore, maths confidence (and maths anxiety) appears to possess incremental validity for predicting maths school grades beyond maths achievement.

Overall, therefore, there is limited evidence of incremental validity for confidence above domain-specific ability for maths scores, and for English ability to a lesser degree. However, despite the apparent overlap between confidence and FFM variables already noted, no study has assessed the incremental validity of the former over the latter. Several studies have been conducted assessing the incremental validity of FFM personality variables above ability measures for academic performance (Chamorro-Premuzic et al., 2006; Furnham et al., 2009; von Stumm, Hell, et al., 2011), and yet this method has not been applied to measures of confidence. Given that the predictive power of cognitive ability measures—particularly Gf and Gc—and certain personality measures (including Conscientiousness and Openness to Experience) for predicting academic outcomes is substantial but by no means comprehensive, it is worth exploring whether something as simple to measure as “online” confidence should be added to this suite of predictors.

3.5 Conclusion

This chapter has surveyed the evidence that has accrued in recent years for both IC and confidence as predictors of AP. Its conclusion is that both IC and confidence show promise as predictors of AP, but in each case the main question is the degree of incremental validity these investment traits possess above the established predictors of cognitive ability and FFM personality. Because of significant overlap between these traits and both intelligence and personality, it is not sufficient that these constructs demonstrate zero-order prediction of AP; they must predict variance over and above the established predictors. For IC, the evidence for this is generally positive, though mixed; and for confidence this approach does not appear to have been conducted. Moreover, these investment traits do not appear to have been studied together, so relatively little is known about their relationship. Therefore, this chapter underscores the need to assess IC and confidence—preferably together—as incremental predictors of AP.

4 Exegesis

4.1 Introduction

This chapter provides an account of the studies assessing the thesis that investment traits intellectual curiosity (IC) and confidence predict academic performance (AP). Although these studies are significant in several other respects—regarding Cattell's investment theory of intelligence, the measurement of the broad Openness/Intellect domain, and other potential investment traits including confidence—they were prompted by recent interest in IC as it relates to academic outcomes, especially the meta-analysis of von Stumm, Hell, et al. (2011). Here, each study will be outlined briefly and considered for its relevance to this thesis.

4.2 Study 1

The aim of the first study (published as Powell, Nettelbeck, & Burns, 2016) was to assess the number of factors to be found across several measures of IC. As several researchers have noted (Fleischhauer et al., 2010; Mussel, 2010; Rocklin, 1994; von Stumm, Hell, et al., 2011; Woo et al., 2007), several scales have been developed in distinct domains of research that appear to measure the same broad construct of IC. Therefore, to assess the importance of IC in predicting AP, it is important to ensure that IC is being measured appropriately, and that results using different scales are broadly comparable. Factor analyses of the several scales have reported different numbers of factors, with TIE containing as many as five factors (Ferguson, 1999), NFC up to three (Furnham & Thorne, 2013), and EC possessing up to two factors (Litman, 2008). Moreover, the study of Powell and Nettelbeck (2014a) indicated that whereas TIE showed (modest) evidence of incremental validity above cognitive ability and

Conscientiousness, NFC, EC and IPIP-Intellect did not. This raised the question of whether these scales measure the same broad construct, or perhaps different profiles of factors.

To assess this issue, the first study was an exploratory factor analysis of items pooled from across TIE, NFC, and EC scales. Specifically, it assessed three research questions: (1) How many factors exist in the general domain occupied by TIE, NFC, and EC? (2) Do all these factors load substantially onto a higher-order factor? (3) Which factors do each scale measure? First, results suggested that six factors spanned these scales, labelled *Intellectual Avoidance*, *Deprivation*, *Problem Solving*, *Abstract Thinking*, *Reading*, and *Wide Interest*. Second, analysis using the Schmid-Leiman rotation (Schmid & Leiman, 1957) indicated that although five of these factors loaded predominantly on an orthogonal higher-order factor, *Reading* items loaded predominantly on their first-order factor. This indicated that *Reading* items from the TIE scale may not fit within this broad domain. And third, relative importance regression assessed the degree to which each scale measured each factor. Results suggested that NFC mostly measured *Intellectual Avoidance* and *Problem Solving*, TIE measured all factors except for *Deprivation*, and EC principally measured *Deprivation*. Therefore, despite the strong overlap between these scales and evidence of a substantial higher-order general factor, these scales appeared to measure different profiles of factors within the IC domain. This being the case, the incremental validity of some scales (such as TIE) but not others (NFC and EC; Powell & Nettelbeck, 2014a) may have been due to these different profiles of factors.

Despite these results, however, it remains possible that factor labelled *Intellectual Avoidance* may be a consequence of negatively-worded items.[8] The significance of negatively-worded items in this domain was explored by Bors et al. (2006) for the NFC scale, who reported that correlations between this scale and measures of AP and verbal ability are partly a consequence of negatively-worded items. If so, this would reduce the number of factors across these scales to five, as *Intellectual Avoidance* would simply be the obverse of intellectual engagement. Nevertheless, this probably would have made little difference to subsequent studies, which focussed particularly on the factors *Reading* and *Deprivation*.

4.3 Study 2

The aim of the second study (accepted for publication) was to assess the incremental validity of IC for predicting academic performance. Although this issue was assessed in the earlier study of Powell and Nettelbeck (2014a), its weaknesses of relying on self-report data for AP, omitting a measure of Gc, and measuring only Conscientiousness among FFM variables highlighted the need to assess this issue more stringently. Further, because the *Deprivation* factor within the EC scale measures information-seeking that comes from a perceived lack of knowledge, this study also assessed whether EC-D predicted distinct variance in AP. Moreover, this study included a measure of online cognitive confidence. Confidence has been assessed in several studies as a non-cognitive predictor of AP (Stankov et al., 2012; Stankov et al., 2014), and has been argued to be an important trait in the investment process (Stankov & Lee, 2017). Therefore, despite the largely negative result reported by Powell

[8] This suggestion was made by an audience member during a conference presentation of this study.

and Nettelbeck (2014a), but also considering other studies that had reported substantial incremental validity for IC (Chamorro-Premuzic et al., 2006), the second study hypothesised that: (1) TIE predicts variance in AP after controlling for Gf, Gc, and FFM personality; (2) EC-D predicts variance in AP after controlling for Gf, Gc, and FFM personality; and (3) Confidence predicts variance in AP after controlling for Gf, Gc, and FFM personality. This appears to have been the first study to assess measures of IC and confidence together as investment traits for AP.

This study used a convenience sample of third-year psychology students who gave permission for their subject grades to be accessed from university transcripts. Hypotheses were tested using three separate stepwise hierarchical regressions where cognitive ability was measured in step one, followed by FFM variables in step two, followed by the relevant investment trait in step three. Results indicated that neither TIE nor EC-D possessed incremental validity for predicting AP above measures of ability and FFM variables, but confidence did. However, confidence and AP related negatively, both within the regression model and when assessed as a zero-order correlation. This finding contradicted the positive relationship usually reported between confidence and AP, and raised doubts about the meaning of this finding. Therefore, when compared within the same study, confidence appeared to have more promise as an investment trait for academic outcomes than did IC—although this finding would need to be replicated to be stated with more certainty. This study provided further evidence that the incremental validity of IC for predicting AP may be highly variable, and cannot be assumed to be present in all educational settings.

This study also contained a significant limitation seen in the data: a lack of correlation between AP and both Gf and Gc. This unusual finding may be explained by two observations: (1) the sample had a strong restriction of range for ability, as they were advanced final-year psychology students at a competitive Australian university; and (2) the variable for AP appeared to contain a strong degree of error variance. This variable was derived by calculating a two-year average grade using not only different psychology subjects, but including subjects from other majors and electives taken from diverse university offerings. Variations in assessment methods and marking standards across university faculties may have made these scores more variable than scores obtained from a more uniform curriculum. Moreover, error variance may also have been introduced by the differing numbers of subjects used to calculate this grade. Many psychology students at this university study part-time, and calculating an average grade from fewer subjects produces more error variance. Because of this, AP scores for students enrolled less than 75% of a full-time load were excluded from analysis, reducing the degree of error for the measure of AP, but also reducing the sample size. It is likely that this error variance attenuated the relationships between AP and other variables without affecting other correlations.

In this situation, therefore, it is likely that the most powerful predictors of AP (e.g. Conscientiousness) still predicted substantial variance in AP amidst the error variance (such as Conscientiousness), but those whose contribution was already attenuated due to restriction of range did not (such as Gf and Gc). This might also explain why the results of study two differed from those of Chamorro-Premuzic et al. (2006) who also assessed the incremental validity of TIE above intelligence and FFM personality in university psychology students. If the course offerings at their university were more uniform, and grades were produced using more stringent standardisation procedures, this might explain the larger amount of overall variance explained by TIE in their model (between 13.0% and 29.2% of variance in AP, depending on the assessment method) compared with the present study (13.6% of variance in AP). Therefore, in addition to its conclusion regarding investment traits, the second study indicated that differences in cohorts and university standards have the potential to affect the degree of incremental validity for IC as a predictor of AP.

4.4 Study 3

The third study (written for publication) had two main aims: to assess Cattell's investment theory in an adult population, and to assess whether reading habits should be incorporated within the Intellect framework (Mussel, 2013a).

The background to this study was an aspect of Cattell's investment theory that has sometimes been overlooked: the distinction between how investment operates in adolescents compared with adults. Cattell argued that the compulsory education system in adolescence largely was responsible for the existence of the broad Gc factor. However, once students had left compulsory education and entered working life, Cattell expected that this factor would become highly tenuous, leading potentially to as many Gc factors as there are occupations, and making the investment process more difficult to assess in adults. However, it became apparent that university psychology students provided an opportunity to assess investment theory in adults: they are exposed to a common curriculum over several years, and therefore the influence of investment traits on investment outcomes might be observable in this group. Moreover, Cattell also distinguished between different types of Gc, including between the broad Gc factor and AP. Because many of the recent studies on investment traits in adults had used AP as the investment outcome, it seemed useful to obtain a measure of Gc that was distinct from AP to see if this might produce a different result.

Given the perspective of investment theory, especially its prediction that strength of investment from Gf into Gc would be influenced by investment traits, six hypotheses were proposed: (1) IC possesses incremental validity above Gf for domain-specific knowledge; (2) IC moderates the relationship between Gf and domain-specific knowledge; (3) Confidence possesses incremental validity above Gf for domain-specific knowledge; (4) Confidence moderates the relationship between Gf and domain-specific knowledge; (5) Items designed to measure an Intellect–Read factor will load substantially on a general factor from across the Intellect scale; and (6) When assessed in a latent variable model consistent with the Intellect framework, variables Learn and Read will associate at close to unity.

An initial phase of this study involved developing a measure of domain-specific psychology knowledge, and a reading scale to complement the Intellect scale. The experimental measure of domain-specific psychology knowledge (with "online" confidence ratings attached) and the measures of Gf and Gc were administered to participants under test conditions as part of a class lecture, and the other variables (including personality variables) were collected online. Regarding investment theory (hypotheses 1–4), only hypothesis 3 was supported, wherein confidence predicted variance in domain-specific knowledge above that predicted by Gf. Contrary to investment theory, no evidence of moderation was found for any investment trait. However, the strength of this study was hampered by the poor reliability of the measure of domain-specific knowledge.

Concerning reading habits, both hypotheses 5 and 6 were supported. The *Intellect–Read* scale was highly reliable, and its items appeared to be indistinguishable from the original items. Moreover, the path model that included the *Read* operation indicated that *Learn* and *Read* operations overlapped at close to unity, indicating that the essence of reading habits was already captured by items that assessed the *Learn* operation. In conclusion, confidence showed more promise than did IC as a potential investment trait, and there appeared to be no clear benefit from incorporating reading habits within the Intellect framework.

4.5 Study 4

The aim of the fourth study (written for publication) was to critically assess the meta-analysis of von Stumm, Hell, et al. (2011) which concluded that IC was the "third pillar" of academic performance alongside cognitive ability and Conscientiousness. This analysis was prompted by the inconsistent results produced by several studies on assessing this question, especially comparing the negative results of the second study with positive results of Chamorro-Premuzic et al. (2006). This inconsistency was also indicated by the correlations used in the meta-analysis of von Stumm, Hell, et al. (2011) to estimate the relationship between TIE and AP, which ranged from $r = .04$ (Goff & Ackerman, 1992) to $r = .37$ (Wilhelm, Schulze, Schmiedek, & Süß, 2003).[9] This critique was an effort to understand how a meta-analysis could conclude that IC was an important factor in AP when the underlying data appeared to be contradictory.

This critique comprised four stages, and argued that: (1) von Stumm, Hell, et al. (2011) miscalculated the correlation between TIE and AP by treating the results of a single study as two correlations, which widened the possible estimates for this value; (2) the incremental validity of TIE varies substantially by study; (3) considering the

[9] This final correlation was originally $r = -.37$ because in the German education system lower numbers indicate higher AP. Appropriately, it was reversed by von Stumm, Hell, et al. (2011).

strong correlation between TIE and NFC, the best estimate of the correlation between TIE and AP may be closer to $r = .2$ than .3; and (4) when the value of the correlation between NFC and AP was substituted within the final model of von Stumm, Hell, et al. (2011), the distinct value of TIE diminishes substantially. It concluded that the true correlation between TIE and AP was difficult to ascertain because of very limited data, but is likely to be lower than von Stumm, Hell, et al. (2011) estimated. Therefore, the definitive study on the relationship of IC with AP had yet to be conducted.

Moreover, although this was not stated in the critique itself, this assessment also raised the issue of the value of path models derived from meta-analytic coefficients. The variability in the correlations between measures of IC and AP appeared to be not only due to measurement error, but a consequence of underlying differences in the cohorts themselves. For instance, to assume that the associations between measures of IC and AP are the same for secondary and tertiary student populations requires substantiation; there are sound reasons to expect this not to be the case. But then to produce a correlation matrix using several such meta-analyses—possibly derived from entirely different cohorts—and to use this as the basis for a path analysis that confidently attributes variance to the different predictors seems to permit a significant degree of uncertainty into the final model. Although this approach might be valid if applied to a large sample of studies that had strong evidence of being representative, the fact that the TIE–AP meta-analytic correlation was based on only three highly variable correlations gives little confidence that these requirements have been met. The issues raised by the fourth study indicate that the final model of von Stumm, Hell, et al. (2011) may not accurately represent the true relationship between these variables; the question that remains is the degree to which this is so.

4.6 Conclusion

This series of studies has relevance for the thesis that IC and confidence are investment traits that predict AP. It suggests that the incremental validity of IC may have been overstated and requires more research; and that although the present studies suggest that confidence has more promise as an investment trait for AP than does IC, this too requires more evidence to substantiate fully. Overall, this has the effect of re-opening for investigation what von Stumm, Hell, et al. (2011) presented as a closed-case.

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Contribution to the Paper	Study concept and design, data collection, statistical analyses, writing and submitting manuscript, addressing referee comments.		
Overall percentage (%)	80%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	11/4/17

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);
ii. permission is granted for the candidate in include the publication in the thesis; and
iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

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Signature		Date	6/4/17

5 STUDY 1: DECONSTRUCTING INTELLECTUAL CURIOSITY

5.1 Abstract

Scales of Need for Cognition (NFC), Typical Intellectual Engagement (TIE), and Epistemic Curiosity (EC) measure intellectual curiosity (IC). These scales correlate strongly and have been factor-analysed individually but not together. Here N = 396 (143 males) undergraduates completed measures of NFC, TIE, and EC. Six factors, labeled *Intellectual Avoidance*, *Deprivation*, *Problem Solving*, *Abstract Thinking*, *Reading*, and *Wide Interest*, were identified. TIE is the broadest scale, measuring all factors except *Deprivation*; NFC measures *Intellectual Avoidance* and *Problem Solving*, plus *Abstract Thinking* and *Deprivation* to a lesser degree; and EC largely measures *Deprivation*. Moreover, *Reading* may not fit in the IC domain; higher-order factor analysis indicated that, whereas items measuring *Reading* loaded more strongly on their first-order factor, items measuring the other factors strongly loaded on a general factor of IC. These results are significant for understanding the contents of these scales, and for future scale development.

5.2 Introduction

Human curiosity is a topic of current research interest, and has been applied to predicting job performance (Mussel, 2013b), academic achievement (von Stumm, Hell, et al., 2011), and exploratory behavior (Litman, Hutchins, et al., 2005). Loewenstein (1994) identified two "waves" of research: the first in the 1950s and '60s addressed the psychological foundations of curiosity and the second in the '70s and '80s concerned its measurement and dimensionality. Given this revival, we may label current interest as the "third wave" of curiosity research.

Berlyne (1950, 1954) provided an early, influential account of curiosity, distinguishing perceptual curiosity (the desire for sensory experience) from epistemic curiosity (EC; the desire for knowledge). The Epistemic Curiosity Scale (Litman, 2008) is the most current scale of EC, measuring "interest" (I-type) and "deprivation" (D-type) factors. EC has been related to feeling-of-knowing and exploratory behavior (Litman, Hutchins, et al., 2005), ambiguity tolerance, and need for closure (Litman, 2010).

Researchers (Mussel, 2010, 2013a; von Stumm, Hell, et al., 2011) have identified measures developed separately from EC but which address similar constructs, specifically, Need for Cognition (NFC) and Typical Intellectual Engagement (TIE). Cohen et al. (1955) defined NFC as a person's need to make sense of his or her experiential world. Cacioppo and Petty (1982) adopted the term, but defined it as "the tendency for an individual to engage in and enjoy thinking" (p. 116). NFC has been applied in many areas, including marketing, behavioural medicine, and education (Cacioppo et al., 1996).

Cacioppo and Petty (1982) developed a 34-item NFC measure, later condensed to 18-items (Cacioppo et al., 1984). While a single factor has routinely been extracted from either scale (Cacioppo et al., 1996), a number of studies have reported multiple factors. For the 34-item scale, Tanaka, Panter, and Winborne (1988) identified three factors, but used an uncommon true-false response scale, making their results difficult to compare with past research (Cacioppo et al., 1996). Bors et al. (2006) argued that negatively-worded items created spurious factors in their study—when these items were positively re-worded, a single factor emerged. However, Furnham and Thorne (2013) created a positively-worded form of the 34-item NFC scale and reported three factors: "need for cognitive challenge", "need for knowledge and understanding", and "enjoyment of cognitive effort".

For the 18-item scale (Cacioppo et al., 1984), Sadowski (1993) reported a single factor in a sample of undergraduates (N = 1,218). However, two considerations suggest a possible second factor: the first principal component accounted for 30.92% of the variance, while a second accounted for an additional 8.95%; and the second eigenvalue of 1.61 substantially exceeds the cutoff suggested by Horn's (1965) parallel roots analysis to indicate a second factor. Additionally, Davis, Severy, Kraus, and Whitaker (1993), using a sample of 230 undergraduates, reported two factors for the NFC 18-item scale, representing "enjoyment of cognitive activity", and "preference for problem solving"—possibly the putative second factor in Sadowski's (1993) dataset. However, Furnham and Thorne (2013) concluded that a positively re-worded 18-item scale contained one factor, essentially the "need for cognitive challenge" factor of the full scale. Thus, although both scales contain a major factor appropriately labeled "Need for Cognition", the 18-item scale may contain a second factor, and the 34-item scale possibly a third.

Conceptually similar to EC and NFC, TIE was defined by Goff and Ackerman (1992) as "a personality trait hypothesized to relate to typical vs. maximal intellectual performance" (p. 539). Ackerman's PPIK theory (intelligence-as-Personality, -Process, -Interests and -Knowledge) extends Cattell's investment theory of intelligence (1943, 1971) by formally incorporating personality variables such as TIE (Ackerman, 1996). TIE is thus a composite measure, located between intelligence and personality.

The TIE scale contains 59 items relating to intellectual activity (Goff & Ackerman, 1992). Although much research treats TIE as a unitary construct (Chamorro-Premuzic et al., 2006; von Stumm, Hell, et al., 2011), factor analyses have suggested three (Ackerman & Goff, 1994), four (Dellenbach & Zimprich, 2008) and five (Arteche, Chamorro-Premuzic, Ackerman, & Furnham, 2009; Ferguson, 1999) factors. Arteche et al. (2009) labeled the five factors "reading and information seeking", "intellectual avoidance", "directed complex problem solving", "abstract thinking", and "intellectual pursuits as a primary focus." TIE has been of particular interest for education, where it has been used to argue that intellectual curiosity predicts variance in academic success beyond what is explained by intelligence and effort (von Stumm, Hell, et al., 2011).

Research demonstrates that measures of EC, NFC and TIE overlap extensively, shown by strong inter-correlations, substantial shared variance in factor analysis, and similar patterns of association with personality variables. Using German translations of the EC, NFC, and TIE, Mussel (2010) reported strong correlations between all curiosity measures in two samples, ranging from r = .52 for EC-Deprivation and TIE, to

.74 for EC-Deprivation and NFC, while Woo et al. (2007) reported .78 between TIE and NFC. Mussel (2010) also subjected total scores of five curiosity scales to exploratory factor analysis, and reported that one factor explained 67% of the variance. Additionally, Woo et al. (2007) observed very similar associations for NFC and TIE with Five Factor Model (FFM) variables and Autonomous Regulation in Learning measures. However, Mussel (2010) cautioned that the scales may not be identical, as TIE correlated more strongly with Gc than did NFC on account of its "reading" factor. Therefore, despite strong overlap, these scales may also be meaningfully different, highlighting the need to integrate these measures within a broad framework (Mussel, 2010).

Recently, (Mussel, 2013a) outlined such a framework, which not only incorporates existing measures of intellectual curiosity (IC) but also points in new directions. This framework proposes that two dimensions encompass Intellect: "Process" and "Operations". Process refers to consecutive phases in performing an action, and has subcomponents labeled "Seek" (a desire for new intellectual challenges) and "Conquer" (a desire to master current domains of knowledge). Operations reflects a person's preference for engaging in different intellectual activities, labeled "Think", "Learn", and "Create". These operations were developed as counterparts to aspects of intelligence theory, where Think parallels fluid intelligence, Learn parallels crystallised intelligence, and Create parallels creativity. When combined these two dimensions produce six facets which span the conceptual space of Intellect: Seek Think, Seek Learn, Seek Create, and Conquer Think, Conquer Learn, Conquer Create. Mussel (2013a) locates TIE, NFC and EC—plus several other curiosity measures—within this framework. TIE, NFC and I-type curiosity most closely resemble the Seek Think facet, while D-type curiosity was associated with the Conquer Think facet.

Two specifics should be noted about Mussel's (2013a) approach. First, while he measured I-type and D-type EC separately, he treated TIE and NFC as unitary constructs, leaving unanswered the associations between TIE and NFC at the facet level. Second, the TIE scale administered was substantially truncated. The 18-item German version (Wilhelm et al., 2003) was used, which has three factors: "intellectual curiosity", "contemplation", and "reading". However, Mussel (2013a) excluded five reading items, concluding that reading could not be incorporated into the Intellect framework at this stage. This 13-item measure is perhaps somewhat different from the 59-item version, which contains up to five distinct factors; a significant point, because reading is perhaps what distinguishes TIE from other measures such as NFC, and is the main cause of TIE's closer association with Gc (Mussel, 2010).

It is important to examine more closely the relationships between EC, NFC, and TIE. Mussel's (2013a) approach implies that these measures are subsumed by a higher-order factor termed "Intellect", as others have suggested (Tanaka et al., 1988). However, he also noted that the relations between facets, and between facets and a possible higher-order factor, remain unclear. To our knowledge, no study has compared the content of these measures at the factor level using the same dataset. Moreover, if these measures are not importantly different, findings across these constructs could be integrated, allowing the full significance of the Intellect domain to be appreciated.

The present exploratory study has factor analysed the items from EC, NFC, and TIE. It addressed three research questions:

(1) How many factors exist in the general domain occupied by TIE, NFC, and EC?

(2) Do all these factors load substantially onto a higher-order factor?

(3) Which factors do each scale measure?

5.3 Method

Participants

Participants were mostly first-year undergraduate psychology students from the University of Adelaide, who received course credit for their involvement. All were informed only that the study aimed to investigate the relationship between IC and academic performance. Data were collected on two occasions: 225 responses from May-to-October 2012 within an earlier study (Powell & Nettelbeck, 2014a), and another 176 from April-to-June 2014. Means and standard deviations for all measures were very similar for both datasets. Five incomplete cases were excluded, leaving n = 396 (253 females), with mean age 20.2 (SD = 3.92 yrs) for the final analysis.

Measures

Epistemic Curiosity (EC). The 10-item Epistemic Curiosity Scale measures interest (I) and deprivation (D) factors for EC. Responses were on a 4-point Likert-type scale (1 = “almost never” to 4 = “almost always”). Higher scores indicate higher EC. Litman (2008) has reported acceptable internal consistency reliability (I-type: α = .82; D-type: α = .76), with a correlation r = .47 between the two factors, together with evidence that I-type curiosity relates to intrinsic motivation, whereas D-type curiosity relates to extrinsic motivation (Litman et al., 2010).

Need for Cognition (NFC). Cacioppo et al. (1984) developed the 18-item NFC scale as an efficient measure for engagement in effortful thought. Despite having less evidence of dimensionality than the 34-item version, the 18-item scale was deemed sufficient for two reasons: (1) most researchers have used the 18-item scale, making results from this analysis relevant to more studies; and (2) of the 16 NFC items excluded by the short form, seven are identical with items in the TIE scale, and an eighth has a close conceptual parallel. Given that the TIE scale was also administered here, using the NFC short form eliminated some redundant questions and shortened administration times.

Responses were on a 9-point Likert-type scale (-4 = "very strong disagreement" to +4 = "very strong agreement"). Higher scores indicate higher NFC. The scale has high internal consistency reliability of α = .9; (Cacioppo et al., 1984), with good construct validity indicated by correlation with the 34-item version and with measures of social anxiety, intrinsic motivation and grade point average (Cacioppo et al., 1996).

Typical Intellectual Engagement (TIE). Participants responded to 59 items on a Likert-type scale (ranging from 1 = "strongly disagree" to 6 = "strongly agree"). Higher scores indicated higher TIE. Pronouns were changed from "you" to "I", "me" or "my" for questions 2, 3, 5, 13, 23, 35, 57 and 58 to make statement styles uniform. Internal consistency has been reported as α = .92 (Goff & Ackerman, 1992), and test-retest reliability as .82 from two unpublished studies (cited by Chamorro-Premuzic et al., 2006). Validity has been demonstrated by studies (Goff & Ackerman, 1992) investigating TIE's distinctness from five-factor domains (Costa & McCrae, 1992a) and its strong correlations with similar scales (Mussel, 2010).

Procedure

Participants completed the questionnaires on SurveyMonkey with no time-limit (2012: *M* = 36.8 min, *SD* = 36.1; 2014: *M* = 19.1 min, *SD* = 21.5)[10]. The 2012 survey contained nine sections: section 1 (information and consent); section 2 (age, gender, participation ID); section 3 (Conscientiousness items from the Quick Scales measuring the FFM; Brebner, 2003); sections 4 through 7 (IPIP-Intellect; Goldberg, 1999, then TIE, EC, NFC, respectively); section 8 (Raven's Advanced Progressive Matrices—Short Form); and section 9 (contact details for debriefing). Section 8 was excluded from the 2014 collection[11], while International Personality Item Pool (IPIP; Goldberg, 1999) Intellect and Conscientiousness were measured but are not analysed further here. Details unique to the 2012 study have been reported elsewhere (Powell & Nettelbeck, 2014a). Analyses were conducted in SPSS Statistics Version 22, except for relative importance regression, conducted in *R* Studio Version 0.98.1103 (R Development Core Team, 2014) using "relaimpo" package Version 2.2-2 (Grömping, 2006).

5.4 Results

Descriptive Statistics

Descriptive statistics and reliabilities are shown in Table 5.1. Alpha coefficients were high, as were correlations between measure of IC (NFC and TIE = .86, NFC and EC = .69, TIE and EC = .71; all $p < .01$). Means for TIE and EC were close to those previously reported (Ackerman, Kanfer, & Goff, 1995; Chamorro-Premuzic et al., 2006;

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[10] The large standard deviations were probably due to the small number participants who took an exceptionally long time to complete the surveys, presumably in multiple sittings.
[11] This exclusion explains the difference between the administrations in average completion times.

Goff & Ackerman, 1992; Litman, 2010), but the mean for NFC (9.22) was somewhat lower than reported by (Sadowski, 1993; Tidwell, Sadowski, & Pate, 2000). No sex differences were found for TIE ($p = .32$) or EC ($p = .07$), but males reported significantly higher NFC than females ($r = .16$, $p = .002$).[12] Previous studies have generally found no sex differences (Cacioppo et al., 1996), though Tanaka et al. (1988) reported higher female scores for the *cognitive persistence* factor.

Table 5.1

Variable means and standard deviations, range of scores, and internal consistency (alpha)

Variable	*M*	*SD*	Range		Alpha
			Potential	Actual	
TIE	226.05	32.10	59-354	119-313	.92
Males (*n* = 143)	228.18	34.13			
Females (*n* = 253)	224.85	30.90			
EC	25.52	5.51	10-40	13-40	.86
Males (*n* = 143)	26.18	5.58			
Females (*n* = 253)	25.14	5.44			
NFC	9.22	21.64	-72 to 72	-63 to 66	.92
Males (*n* = 143)	13.74	22.42			
Females (*n* = 253)	6.66	20.81			

Note. TIE = Typical Intellectual Engagement; EC = Epistemic Curiosity; NFC = Need for Cognition.

[12] Eight NFC items had higher scores for males than females: four (1, 2, 6 and 13) had primary loadings on Problem Solving, two (7 and 9) on Avoidance, and two (10 and 14) on Abstract Thinking, with no sex differences for the other items. This sex difference is an issue for future research.

Factor Analysis of EC, NFC and TIE Scales Combined

Fabrigar, Wegener, MacCallum, and Strahan (1999) recommended using multiple methods to determine the number of factors in a dataset, including the scree test, parallel analysis, and fit as measured by the Root Mean Square error of Approximation (RMSEA; Steiger, 1990) . Using Principal Component Analysis, the scree plot showed clear breaks after the first and sixth components, while parallel analysis using both the mean and a more conservative 95th percentile cutoff indicated six factors. Using Maximum Likelihood estimation, RMSEA steadily improved when comparing one- through seven-factor solutions, and a six-factor solution was a close fit (RMSEA = .045, 90% CI .033—.054) and was only marginally improved by adding a seventh factor (RMSEA = .043, 90% CI .032—.053). Therefore, given that this six-factor solution was also clearly interpretable, it was retained for subsequent analysis—thus addressing our first research question.

To extract the six factors, we used Maximum Likelihood extraction with Promax rotation. Due to the large number of items (87), matrices of factor loadings and correlations are presented in Appendices 1, 2, and 3. A rotated factor loading of .3 was considered salient yielding 73 items with salient loadings and nine cross-loading items.[13] In consultation with prior analyses (Arteche et al., 2009; Ferguson, 1999; Litman, 2010), the six factors in the general IC domain were labeled: *Intellectual Avoidance*—avoiding activities that require intellectual effort (negatively-scored);

[13] Six items in the NFC and TIE scales are identical. We decided to retain the identical items, permitting a more accurate assessment of the relationship between these scales and our six-factors solution. However, we also tested the solution with the identical items removed, and the factor structure did not change in a meaningful way.

Deprivation—feeling discomfort about unsolved problems; *Problem Solving*—enjoying complex problem solving; *Abstract Thinking*—enjoying thinking about abstract and philosophical matters; *Reading*—frequency and enjoyment of reading; and *Wide Interest*—being interested in a wide range of topics.

Schmid-Leiman Higher-Order Factor Analysis

To elucidate further the relationships between these factors, we employed a Schmid-Leiman solution (Schmid & Leiman, 1957). Higher-order factor analysis derives its most general factors from correlations between first-order factors, obscuring the relationship between variables and higher-order factors. Schmid-Leiman analysis, however, derives higher-order factors from the primary variables, attributing the remaining variance to first-order factors. This approach assesses whether questionnaire items relate more closely to the general factor or their first-order factor. The present dataset was well suited to such analysis, with substantial inter-factor correlations suggesting a higher-order factor.

A dominant, general factor explained two-thirds (66%) of the variance in the model, and first-order factors explained the remaining third (34%). However, clear differences emerged in the relationships between first-order factors and the general factor. Ordered from most to least general, *Problem Solving* (81%) and *Intellectual Avoidance* (77%) relate very strongly to the general factor, capturing the essence of this broad domain. Still general but to a lesser degree were *Abstract Thinking* (65%), *Deprivation* (60%), and *Wide Interest* (55%). However, *Reading* (34%) is clearly distinct, with items relating more closely to the first order factor than the general domain.

Therefore, the short answer to our second research question is “No”; while other items relate more substantially to the general domain, items loading on *Reading* relate more strongly to their first-order factor.

Relative Importance Regression of IC Scales on Factors

To assess the degree to which the original scales were measured by these six factors, we used regression analyses. When NFC was regressed on scores for the six factors ($F(6,389) = 1165.3$, $p < .001$, $R^2 = .95$), regression coefficients for all factors were significant except for *Reading* ($p = .77$) and *Wide Interest* ($p = .12$). For TIE ($F(6,389) = 1171.2$, $p < .001$, $R^2 = .95$), regression coefficients for all factors were significant. And for EC ($F(6,389) = 532.5$, $p < .001$, $R^2 = .89$) all factors except *Reading* ($p = .80$) were significant.

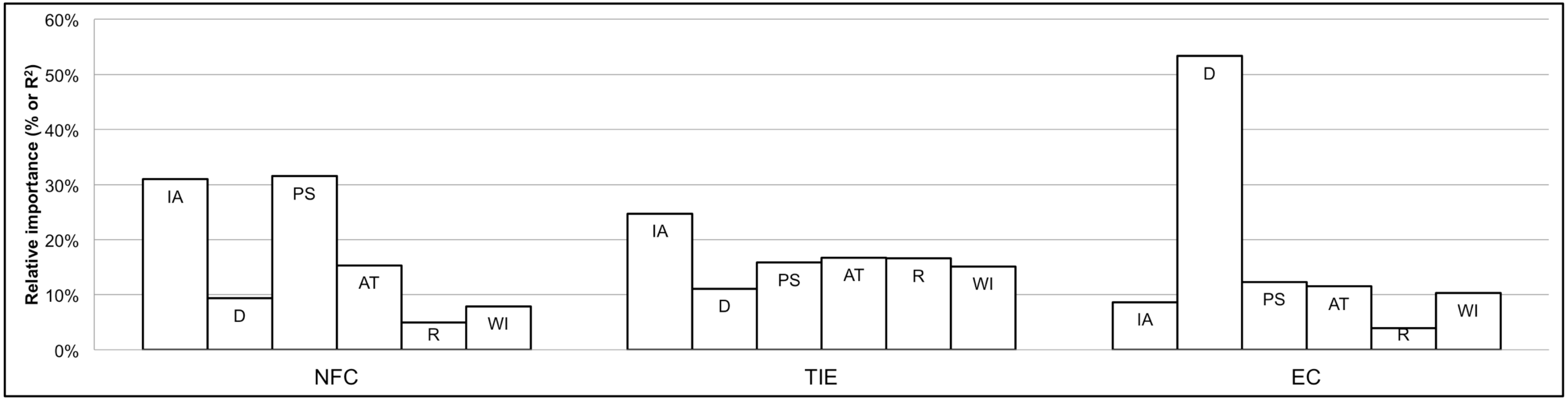
Relative importance regression is a computationally intensive approach to the problem of assessing the relative contributions of correlated regressors to a regression model (Grömping, 2006). This approach decomposes the full variance explained by a regression model into regressor-specific percentages, by averaging the regressor-specific variance across all possible orderings of regressors. Of the approaches available for dominance analysis, we used the LMG method (Lindeman, Merenda, & Gold, 1980) recommended by Grömping (2006).

Results for the relative importance analysis for NFC, TIE, and EC are presented in Figure 5.1. NFC appears to largely measure *Intellectual Avoidance* (31%) and *Problem Solving* (32%), and captures *Abstract Thinking* (15%) to a lesser degree. TIE captures all factors substantially, with more variance explained by *Intellectual Avoidance* (25%) and less by *Deprivation* (11%) than the other factors (range 15-17%). The variance explained by EC, however, is dominated by *Deprivation* (53%), with the other factors to a lesser extent (range 4-12%).

Therefore, addressing our third research question, we concluded that: TIE is the broadest scale, measuring all factors robustly except, arguably, *Deprivation*; NFC (18-item) predominantly measures *Intellectual Avoidance* and *Problem Solving*, plus *Abstract Thinking* and *Deprivation* to a lesser degree; and EC largely measures *Deprivation*.

Figure 5.1

Relative importance regression models



Note: Relative importance regression models of factors contributing to scores for Need for Cognition (NFC), Typical Intellectual Engagement (TIE), and Epistemic Curiosity (EC). The relative importance of regressions total 100% for each scale. IA = Intellectual Avoidance; D = Deprivation; PS = Problem Solving; AT = Abstract Thinking; R = Reading; WI = Wide Interest.

5.5 Discussion

These results are substantive in a number of respects, especially concerning previous factor analyses, Mussel's proposed Intellect framework, and future directions for measures within this domain.

Previous Factor Analyses

Regarding EC, the items measuring I-type are spread across a number of the factors, suggesting that it can be used as a very short, broad measure of this general domain. However, items measuring D-type curiosity are unique, capturing an aspect of EC not effectively measured elsewhere. NFC items spanned a number of factors, suggesting that it is a broader measure that some prior analyses would suggest—although when this scale is considered in isolation there may not be enough factor-specific items to demonstrate this diversity.

Our analysis of TIE closely matches the analyses of Ferguson (1999) and Arteche et al. (2009), except that the contents of our *Wide Interest* factor are slightly different to Ferguson's (1999) *intellectual pursuits as a primary focus*. TIE has clearly the broadest content, measuring all factors except perhaps *Deprivation*. Although other studies have labeled the contents of our *Wide Interest* factor "intellectual curiosity", we prefer to reserve this term for the broad domain because it may be unhelpful to use the same label for both the general and a specific factor when they have only a modest association.

Mussel's Intellect Framework

Two-thirds of the variance in scale items across the three IC measures included in our study is explained by a general factor, which clearly implies a higher-order factor—very similar to Intellect (Mussel, 2013a). Moreover, the *Reading* factor was the most independent, with its items sharing only one-third of their variance with the broad domain. This supports Mussel's (2013a) finding that *Reading* could not be incorporated within the Intellect domain. One obvious difference between our results and those of Mussel (2013a) is his inclusion of the aspect of creativity, as implied by intelligence theory. None of the six factors identified here address creativity, so the addition of creativity is a new direction.

Limitations

As noted, we used the condensed 18-item NFC scale instead of the 34-item original. Using the larger measure may have provided another eight distinct questions at the cost of further redundancy. But having inspected the content of these eight items, we doubt that our results would have changed through their inclusion. Furthermore, a different factor structure might obtain in a non-student cohort, which would limit the generalisability of our results. Finally, the *Avoidance* items were negatively-worded, meaning that this factor could be an artifact of method. These remain issues for future research.

Future Directions

These results support using Mussel's Intellect framework for future research, which represents Intellect as possessing higher-order and first-order factors—as found here. Further, *Deprivation* is distinct from the factors found in TIE, justifying its reconfiguration as the Conquer process of Mussel's Intellect framework. Moreover, consistent with Mussel (2013a), *Reading* does not clearly fit within the IC domain. This is surprising because reading appears to be a key habit for active minds. However, the TIE scale was developed over two decades ago, and reflects the information-seeking habits of that time—mainly printed books and magazines. Updating reading items to include screen-based reading habits might increase the loading of this factor on IC in a modern cohort.

Finally, studies suggest that measures of IC may usefully predict both academic (von Stumm, Hell, et al., 2011) and workplace performance (Mussel, 2013b) beyond established predictors. Given that we found no evidence that TIE, NFC or EC measure creativity, future research should investigate whether creativity improves criterion validity in these domains.

Statement of Authorship

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Principal Author

Name of Principal Author (Candidate)	Christopher Powell		
Contribution to the Paper	Study concept and design, data collection, statistical analyses, writing and submitting manuscript, addressing referee comments.		
Overall percentage (%)	80%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	11/4/17

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);
ii. permission is granted for the candidate in include the publication in the thesis; and
iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

Name of Co-Author	Ted Nettelbeck		
Contribution to the Paper	Principal supervision, advice about study concept and design, manuscript proofreading and approval.		
Signature		Date	21.3.17

Name of Co-Author	Nicholas R. Burns		
Contribution to the Paper	Co-supervision, advice about statistical analyses, manuscript proofreading and approval.		
Signature		Date	6/4/17

6 Study 2: The Incremental Validity of Intellectual Curiosiy and Confidence for Predicting Acadmic Performance in Advanced Tertiary Students

6.1 Abstract

Intellectual curiosity is a topic of research interest and often predicts academic performance (AP). However, evidence for its incremental validity, which the present study aimed to assess, is mixed. Participants were 216 (52 males, 151 females, 13 not reported) third-year psychology students (age *M* = 23.0 yrs) who completed tests of fluid and crystallised intelligence, five-factor model (FFM) personality, intellectual curiosity, and confidence. AP was obtained from university transcripts. No incremental validity above intelligence and FFM personality was found for measures of curiosity or confidence. In all analyses, Conscientiousness was the most substantial predictor of AP. Future research may focus on the conditions in which curiosity or confidence predict AP.

6.2 Introduction

The relationship between intelligence and curiosity has long been a topic of research, generating theories relating to different stages of human development. We survey these approaches, before addressing curiosity and other constructs as predictors of academic performance (AP).

Curiosity through the years

Berlyne (1950) viewed curiosity as an exploratory drive in animals and humans, excited by novel stimuli. He distinguished between curiosity for sensory experience (perceptual curiosity) and curiosity for knowledge and understanding (epistemic curiosity; Berlyne, 1954)—also called intellectual curiosity (IC; von Stumm, Hell, et al., 2011).

For infants, Fagan (1970) developed the concept of "preference for novelty", suggesting that infants who give more attention to novel stimuli demonstrate more effective information processing—a basis for the emergence of intelligence (Fagan, 2000). This method predicts later IQ and AP (Fagan et al., 2007), and demonstrates continuity for intelligence through life. However, this relationship between intelligence and curiosity for infants should not be assumed to hold in later years.

Based on research with adolescents, Cattell (1963) strengthened his theory of fluid (Gf) and crystallised (Gc) intelligence, where Gf is genetically-determined abstract reasoning ability, and Gc is acquired knowledge. He explained their substantial correlation by his "investment theory" that Gf was "invested" in Gc over time. He also posited the importance of "investment traits", such as interest and curiosity, that determined the strength of this investment (Cattell, 1963, 1987). Cattell proposed that the school curriculum provided the basis for Gc as a broad factor, and that the relationship between Gf and Gc would weaken in the years following compulsory education.

More recently, Ackerman (1996) developed his PPIK (process, personality, interests, knowledge) theory of adult intelligence. Extending Cattell's theory, PPIK retains the idea that Gf (process) is invested in Gc (knowledge), and formally incorporates the place of interest and personality variables in this process. Goff and Ackerman (1992) developed the Typical Intellectual Engagement (TIE) scale as a measure of IC, which has been used in subsequent research. Thus, the proposed relationship between intelligence and curiosity becomes more complex with age.

Additionally, two other measures of IC are of special interest: Need for Cognition (NFC; Cacioppo & Petty, 1982) and Epistemic Curiosity (EC; Litman, 2008). Although TIE, NFC and EC originated in separate research contexts, their strong intercorrelations and lack of discriminant validity suggest that they might be used interchangeably (Mussel, 2010; Woo et al., 2007). NFC describes a tendency to enjoy cognitively stimulating activities or (negatively) the tendency to avoid thinking (Cacioppo et al., 1996). EC is subdivided into "interest" (EC-I) and "deprivation" (EC-D) factors, where EC-I is similar to TIE and NFC, and EC-D relates to discomfort arising from perceived lack of information (Litman, 2008). Powell et al. (2016) conducted an exploratory factor analysis across TIE, NFC and EC scale items, and concluded that EC-D is unique to the EC scale. Because its items measure tenaciousness in curiosity (e.g. "I work like a fiend at problems that I feel must be solved"), it merits investigation as a predictor of AP. The incremental validity of IC will be addressed below.

Another potential investment trait is confidence (Stankov et al., 2012). Confidence can be measured as a dimension of personality or “online”, where, after answering a problem, participants are asked: “How confident are you that your answer is correct?” (Burns et al., 2016). Online confidence is a robust general trait distinct from Gf and Gc (Kleitman & Stankov, 2007) that predicts AP better than self-efficacy, self-concept, and anxiety (Stankov et al., 2012). Because of these qualities, confidence also warrants investigation as an investment trait alongside IC, and as a predictor of AP.

Predictors of AP

We turn now to research on variables that predict AP. General intelligence is the pre-eminent predictor of AP, with reported correlations up to r = .81 (Deary et al., 2007), although other studies have reported around r = .5 (Laidra et al., 2007). Regarding personality, several meta-analyses have reviewed Five Factor Model (FFM; Costa & McCrae, 1992a) variables as predictors of AP. Poropat (2009) concluded that Conscientiousness is a major predictor, and reported that Agreeableness and Openness are more modest predictors. For post-secondary students, Schuler et al. (2007) reported that only Conscientiousness predicted grades consistently. Because intelligence and Conscientiousness tend to negligible (Poropat, 2009) or small negative (Moutafi et al., 2006) correlations, together they predict substantial variance in AP. Moreover, von Stumm, Hell, et al. (2011) reported a meta-analysis in which IC and Conscientiousness together predicted as much variance in AP as did intelligence, concluding that IC is the “third pillar” of academic performance alongside intelligence and Conscientiousness.

However, although these studies suggest that intelligence and personality measures may account for roughly 50% of the variance in AP, this leaves much variance unexplained. Moreover, if variables such as IC and confidence can be modified through intervention, establishing their ability to predict AP provides a basis for improving academic outcomes.

The incremental validity of IC

Current evidence for the incremental validity of IC is inconsistent, and may depend on which measure is of IC is used. Because TIE has been used in several recent major studies we will primarily discuss this measure. Furnham et al. (2009) reported modest incremental validity (about 2–3%) for TIE scores above measures of intelligence and general knowledge for AP in British schoolchildren. Chamorro-Premuzic et al. (2006) reported more substantial incremental validity (about 3–9% depending on assessment method) for TIE above intelligence and FFM variables in predicting AP in university psychology students. Finally, the meta-analytic study of von Stumm, Hell, et al. (2011) concluded that IC is the “third pillar” of AP.

However, two recent studies found little evidence of incremental validity. Powell and Nettelbeck (2014a) reported that TIE predicted limited incremental variance beyond intelligence and Conscientiousness (about 1.8%) for university entrance scores, while other IC measures (including NFC and EC) possessed no incremental validity. TIE may overlap more substantially with Gc than do other IC measures because it measures reading habits (Mussel, 2010), and thus it may be Gc—rather than IC *per se*—that makes TIE a useful, additional predictor of academic success (Powell & Nettelbeck, 2014a). Moreover, Schroeders et al. (2015) reported only limited incremental variance for TIE in high school grades (0.5% for Mathematics, 1.3% for Physics, 1.5% for Biology, and 1.8% for Chemistry) after controlling for socioeconomic status, gender, migration background, Gf, and subject-specific interest. Together, these studies suggest that the incremental validity of TIE may be limited, and may be more substantial for some subject domains than others. The finding that different measures of IC show different patterns of incremental validity raises the question of whether TIE is a "pure" measure of IC, and thus whether the incremental validity of IC has been established clearly.

The present study

Chamorro-Premuzic et al. (2006) and von Stumm, Hell, et al. (2011) measured only general intelligence (*g*), while Powell and Nettelbeck (2014a) measured only Gf, and therefore these studies did not assess Gf and Gc as distinct contributors when predicting AP. Moreover, although Stankov et al. (2012) compared confidence to other measures of self-belief, they did not control for intelligence or personality. These limitations suggest a study that measures intelligence, Conscientiousness, IC and confidence as predictors of AP.

Senior year undergraduate students provide a strong test of the predictive power of personality variables: they have a restricted range for intelligence, potentially allowing personality variables more scope to predict AP (cf. Lievens, Ones, & Dilchert, 2009). Despite mixed evidence, we anticipated small incremental validity for IC. The present study included TIE, NFC, and EC, measures of Gf and Gc, all FFM variables, and confidence. Hypotheses tested were:

(1) TIE predicts variance in AP after controlling for Gf, Gc, and FFM personality.

(2) EC-D predicts variance in AP after controlling for Gf, Gc, and FFM personality.

(3) Confidence predicts variance in AP after controlling for Gf, Gc, and FFM personality.

6.3 Method

Participants

Data were obtained from 219 third-year psychology students at a large Australian university who participated to fulfill a course practicum requirement. Students could withhold their data from analysis (*n* =3), leaving 216 responses. Age (*M* = 23.0, *SD* = 6.20, range 19-62 yrs) and sex (52 males, 151 females, 13 not reported) were reported by 203 students. Tests were administered both in-class and online using SurveyMonkey. Because SurveyMonkey allows participants to complete surveys across multiple occasions, the *M* and *SD* of completion times are affected by several outliers. The median completion time was about 54.5 minutes, and about 2/3 of participants took between 30 and 90 minutes to complete the online component. Because data were missing in each administration, *n*s differed by variable.

Scores below 3 for Advanced Progressive Matrices—Short Form (APM–SF) and Cattell's Assessment Battery—Inductive Reasoning (CAB–I) were considered insincere attempts (*n* = 18 and 13, respectively) and excluded. Scores of AP were retained only for students averaging ≥ 75% subject load across two years (*n* = 146) to allow only robust estimates of academic performance in the analyses. Students were informed only that the practical would explore individual differences in intellectual curiosity and AP.

Measures

Fluid Intelligence (Gf). Raven's Advanced Progressive Matrices—Short Form (Bors & Stokes, 1998) and Inductive Reasoning from Cattell's Cognitive Assessment Battery (Hakstian & Cattell, 1978) measure Gf, and were used to derive scores for Gf.

Crystallised intelligence (Gc). The Mill-Hill (MH) vocabulary test (Raven, Raven, & Court, 1998) and Spot-the-Word test (STW; Baddeley et al., 1993) measure Gc, and were used to derive scores for Gc.

FFM personality (FFM). The OCEANIC scale measures FFM personality traits (Schulze & Roberts, 2006). Here responses were on a 6-point Likert scale (1 = "never" to 6 = "always"), and Cronbach's alphas ranged from .80 (Openness) to .90 (Conscientiousness).

Epistemic Curiosity (EC). The 10-item Epistemic Curiosity Scale measures EC-I and EC-D factors. Here responses were on a 4-point Likert scale (1 = "almost never" to 4 = "almost always"), and Cronbach's alphas were .84 (I) and .86 (D).

Need for Cognition (NFC). Here we used the positively-worded NFC scale of Furnham and Thorne (2013), and responses were on a 7-point Likert scale (1 = "extremely uncharacteristic" to 7 = "extremely characteristic"). Cronbach's alpha was .92.

Typical Intellectual Engagement (TIE). Goff and Ackerman (1992) created the 59-item TIE scale to measure intellectual engagement. We changed pronouns from "you" to "I", "me" or "my" for questions 2, 3, 5, 13, 23, 35, 57 and 58 to make statement styles uniform. In the present study, participants responded on a 6-point Likert scale (1 = "strongly disagree" to 6 = "strongly agree"), and Cronbach's alpha was .94.

Confidence. After each intelligence test item, participants were asked "How confident are you that your answer is correct?" and responded on a scale of 0–100% with anchors at 10% intervals (Stankov et al., 2012). Item-level scores for each scale were averaged across all scale items, and confidence ratings from the four measures were averaged for an overall confidence score.

AP. Each student's average percentage grade across 2014 and 2015 was accessed with the student's permission from official university transcripts.

Procedure

Data were collected in-class and online. Gc measures (including confidence ratings) were administered under supervision in a 50-minute psychology class, with remaining variables collected online. Section 1 was information and consent, and section 2 included student ID, age, sex, degree major. Section 3 measured the APM-SF (with confidence), and section 4 the CAB-I (with confidence). Section 5 measured FFM variables. Sections 6 to 8 measured NFC, EC, and TIE respectively. Section 9 measured reading habits (not analysed further). Data were analysed in SPSS version 23, except for relative importance regressions, which were conducted in *R* (R Development Core Team, 2014).

Statistical analyses

To estimate Gf, the unrotated first principal component for APM–SF and CAB–I scores was extracted. To estimate Gc, the unrotated first principal component for STW and MH tests was extracted.

To assess the incremental validity of measures of IC and confidence above intelligence and personality measures, we compared nested regression models. Given negligible relationships for both TIE and NFC with AP, and their strong correlation with each other (r = .81), we analysed only TIE. For each regression Gf, Gc and FFM personality were entered first (step 1), and TIE, EC-D, or confidence entered next (step 2). Subsequently, relative importance regressions (Grömping, 2006) estimated the weight of each predictor within the final regression model. This approach averages predictor weights across all possible orders of entry, providing a more stable assessment of a predictor's importance to the outcome variable (LMG method; Lindeman et al., 1980).

6.4 Results

Descriptive statistics

Descriptive statistics are presented in Table 6.1. The mean for AP was 70.2%. Mean scores for APM–SF (M = 7.43) appeared to be higher than those reported previously (M = 7.01) in a university sample (Bors & Stokes, 1998), as did scores for CAB-I (males: M = 10.08; females: M = 9.37) compared to those reported previously (males: M = 8.79; females: M = 8.69) in a university sample (Hakstian & Woolsey, 1985). These differences may be due to our exclusion of scores below 3 for both measures, restriction of range, and possibly reflect the Flynn effect (Flynn, 1987). Moreover, because the CAB-I is designed to be administered in 5 ½ minutes (Hakstian & Cattell, 1978), the untimed administration in the present study may have increased scores for this measure. However, because no measure of intelligence in the present study correlated substantially with AP, we do not think that a timed administration would have changed any conclusions. Mean scores for measures of Gc (MH = 18.06; STW = 48.26) were substantially lower than those reported in a validation study (24.04 and 53.00 respectively; Baddeley et al., 1993), perhaps due to younger participants (age 23.03 vs 38.00) and the high percentage of international students at our university (about 26%).

Table 6.1

Variable means and standard deviations, range of scores and internal consistency (alpha)

Variable	*N*	*M*	*SD*	Range		Alpha
				Potential	Actual	
Academic performance	146	70.16	9.24	0–100	39.88–90.50	N/A
APM-SF	186	7.43	2.51	0–12	3–12	.70
CAB-I	193	9.55	2.43	0–12	3–12	.75
MH	200	18.06	3.68	0–34	6–30	.70
STW	199	48.26	5.29	0–60	30–58	.85
Openness to Experience	201	32.45	6.84	9–54	17–54	.80
Conscientiousness	201	37.68	7.83	9–54	15–54	.90
Extraversion	201	33.44	7.30	9–54	15–51	.86
Agreeableness	201	43.71	5.40	9–54	23–54	.85
Neuroticism	201	29.49	7.54	9–54	17–53	.87
EC	201	26.04	5.91	10–40	10–40	.89
EC-I	201	14.44	3.06	5–20	5–20	.84
EC-D	201	11.59	3.54	5–20	5–20	.86
NFC	201	163.99	28.05	34–238	81–233	.92
TIE	201	232.39	34.68	59–354	119–319	.94
Confidence	164	67.45	13.26	0–100	30.95–91.76	.96

Note. APM-SF = Advanced Progressive Matrices—Short Form; CAB-I = Cattell's Assessment Battery—Inductive Reasoning; MH = Mill Hill vocabulary scale; STW = Spot-the-Word test; EC = Epistemic Curiosity; EC-I = EC (Interest); EC-D = EC (Deprivation); NFC = Need for Cognition; TIE = Typical Intellectual Engagement.

Mean scores for FFM variables in the present study were broadly consistent with those reported previously (Schulze & Roberts, 2006), although our sample appeared to have lower levels of Conscientiousness, Agreeableness, and Extraversion, and higher levels of Neuroticism.

Correlations between variables are presented in Table 6.2. The correlation between Gf and Gc was $r = .19$, and substantial correlations were found between IC measures, ranging from .51 (EC-D and NFC) to .81 (TIE and NFC). IC measures overlapped most substantially with Openness and Conscientiousness, consistent with previous findings (Goff & Ackerman, 1992). Only Conscientiousness ($r = .32$) and Agreeableness ($r = .18$) directly predicted variance in AP. IC measures (EC-I, NFC and TIE) correlated $r = .16$ with AP, but not significantly (ps = .051, .06 and .06, respectively).

Regressions predicting AP

The regression analyses are reported in Table 6.3. Model 1 was the base model, and included Gf, Gc, and FFM personality variables. Model 2 added TIE to the base model, and found no evidence of incremental validity. Model 3 added EC-D to the base model, and found no evidence of incremental validity. Model 4 added confidence to the base model, and found no evidence of incremental validity. In each model, relative importance regression indicated that Conscientiousness accounted for about 2/3 of the explained variance, whereas no other variables predicted significant variance in AP. Therefore, hypotheses 1, 2, and 3 were not supported.

Table 6.2

Pearson correlations between variables

Variable	Gf	Gc	O	C	E	A	N	EC	EC-I	EC-D	NFC	TIE	Confidence
Academic performance	.01	.06	.07	.32**	.15	.18*	-.06	.05	.16	-.06	.16	.16	-.12
Gf		.19*	.16*	-.19*	-.19*	-.12	-.12	.10	.13	.06	.27**	.20**	.40**
Gc			.27**	-.01	-.01	-.01	.07	.13	.19*	.06	.31**	.35**	.42**
Openness to Experience (O)				.21**	.07	.16*	.17*	.57**	.58**	.45**	.58**	.64**	.40**
Conscientiousness (C)					.27**	.35**	-.04	.15*	.13	.13	.24**	.17*	-.01
Extraversion (E)						.24**	-.30**	.15*	.29**	.01	.19**	.12	.08
Agreeableness (A)							-.07	.07	.13	.01	.18**	.12	-.04
Neuroticism (N)								.08	-.01	.14*	-.17*	-.09	-.05
EC									.88**	.91**	.66**	.69**	.28**
EC-I										.61**	.69**	.72**	.25**
EC-D											.51**	.53**	.24**
NFC												.81**	.46**
TIE													.42**

Note. Gf = fluid ability; Gc = crystallised ability; EC = Epistemic Curiosity; EC-I = Epistemic Curiosity (Interest); EC-D = Epistemic Curiosity (Deprivation); NFC = Need for Cognition; TIE = Typical Intellectual Engagement.

* $p < .05$, 2-tailed.

** $p < .01$, 2-tailed.

Table 6.3

Regression model comparisons for academic performance

	Model 1 (base) $F[7, 107] = 2.39^*$ Adjusted $R^2 = .08$		Model 2 (with TIE) $F[8, 106] = 2.17^*$ Adjusted $R^2 = .08$ Adj. R^2 change = .00		Model 3 (with EC-D) $F[8, 106] = 2.21^*$ Adjusted $R^2 = .08$ Adj. R^2 change = .00		Model 4 (with Confidence) $F[8, 106] = 2.42^*$ Adjusted $R^2 = .09$ Adj. R^2 change = .01	
	β	RI	β	RI	β	RI	β	RI
Gf	.09	.02	.09	.02	.08	.02	.13	.03
Gc	.02	.00	-.01	.00	.02	.00	.08	.02
Openness to Experience	-.09	.02	-.15	.03	-.04	.01	-.04	.01
Conscientiousness	.31**	.72	.31**	.68	.31**	.68	.30**	.61
Extraversion	.13	.15	.13	.14	.12	.13	.13	.13
Agreeableness	.07	.09	.06	.08	.06	.08	.07	.07
Neuroticism	.05	.01	.08	.01	.04	.01	.04	.01
TIE	-	-	.10	.04	-	-	-	-
EC-D	-	-	-	-	-.10	.07	-	-
Confidence	-	-	-	-	-	-	-.18	.11

Note: Gf = fluid ability; Gc = crystallised ability; TIE = Typical Intellectual Engagement; EC-D = Epistemic Curiosity (Deprivation); R^2 change = change from Model 1; RI = relative importance, indicating percentage of total variance attributable to the predictor.

* $p < .05$, 2-tailed.

** $p < .01$, 2-tailed.

6.5 Discussion

Incremental validity of IC

Results support our earlier finding (Powell & Nettelbeck, 2014a) that measures of IC possess limited or no incremental validity above intelligence and personality for predicting AP. Moreover, these results extend the earlier finding by obtaining AP from academic transcripts, measuring IC during the period of assessment for AP, and including a measure of Gc. Current results are consistent with Schroeders et al. (2015), who reported modest incremental validity above background variables (gender, migration, and SES), subject-specific interest, and intelligence. Thus, they add to growing evidence that incremental validity of IC may be limited, at least in certain cohorts.

These results differ from those Chamorro-Premuzic et al. (2006), who found incremental validity for TIE above intelligence and FFM personality for various assessment methods. Their zero-order correlations between TIE and assessment methods were more substantial (range r = .28–.45) than in the present study (r = .16), which reduced our likelihood of finding incremental validity. Moreover, 50% of each psychology course grade at our university is determined by examination—the method of assessment with the strongest relationship to TIE (r = .45) in Chamorro-Premuzic et al. (2006). They also differ from the meta-analysis of von Stumm, Hell, et al. (2011), who concluded that IC is the "third pillar" of academic success. Currently, we cannot give a satisfying explanation for these differences.

EC-D did not incrementally predict AP. Although we expected that those with strong high scores on this scale would strive to master subject content, its negligible correlation with AP did not reflect this. However, because Conscientiousness accounted for about two-thirds of explained variance in AP, this study supports Conscientiousness as the ultimate "investment trait" for academic outcomes.

Confidence

In prior research, confidence is a powerful non-cognitive predictor of AP in secondary students (Stankov et al., 2012). However, in the present study we found a non-significant (and possibly negative) relationship between confidence and AP, and found no evidence of incremental validity. These results may have been due to the highly-selected nature of the sample. We conclude that the role of confidence as an "investment trait" remains a prospect for future research.

Limitations

This study was limited because the CAB-I measure of Gf was untimed, with a ceiling effect suggested by higher average scores than those previously reported. Moreover, the findings are limited to psychology students. Although humanities subjects show the strongest relationship with IC (Rolfhus & Ackerman, 1999), it may be that using students from other disciplines would produce different results. Furthermore, we assessed only total scores for subjects, whereas prior research has shown that the extent of incremental validity for IC varies according to the method of assessment (Chamorro-Premuzic et al., 2006). However, given that the AP scores here are those used to determine entry to postgraduate courses, we think these are the preferred outcome variable. Lastly, the limited sample size of our dataset, especially concerning the main variable of interest (AP), and the small number of males, meant that our conclusions remain tentative, pending a larger, more representative study.

Future directions

Current results suggest that the usefulness of IC and confidence may be limited to certain situations or cohorts. Because the extent of these limits is currently unclear, future research should determine the conditions where these variables possesses incremental validity. Furthermore, despite the results in this study, we think that EC-D has strong face validity for predicting AP. The most recent framework measuring IC is Intellect, developed by Mussel (2013a), whose *Seek* and *Conquer* processes overlap with EC-I and EC-D respectively. This scale might be used in future research. Future research should also assess the incremental validity of confidence in a less-selected sample. Finally, IC remains of special interest as a personality variable that usually predicts AP, and possibly is open to intervention (von Stumm, Hell, et al., 2011). If so, future research should assess the effectiveness of interventions that aim to inspire IC in students.

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By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);
ii. permission is granted for the candidate in include the publication in the thesis; and
iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

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7 Study 3: Testing Investment Theory and the Intellect Scale in University Students

7.1 Abstract

The investment theories of Cattell and Ackerman suggest that "investment traits" are important factors in the investment of fluid intelligence (Gf) and crystallised intelligence (Gc) over time. The present study aimed to assess the two investment traits of intellectual curiosity (IC) and confidence as predictors of domain-specific knowledge, and the place of reading habits in the domain of IC. Participants were 162 (47 males) third-year psychology students (age M = 23.53) who completed measures of Gf, Gc, domain-specific psychology knowledge, confidence, IC, and IC reading habits. Results indicated that IC did not predict variance in domain-specific knowledge above intelligence, but that confidence did. We also tested whether IC or confidence moderated the influence of Gf on domain-specific knowledge, and they did not. Moreover, although reading habits could be re-incorporated within the IC domain, we doubt that this is necessary. However, the reliability of our measure of domain-specific knowledge was poor, and this limits the strength of our conclusions. We discuss these results in the context of investment theory, and suggest that confidence holds the most promise as a key variable in the investment process.

7.2 Introduction

Investment theory

In the history of research on human intelligence, an enduring question concerns the relationship between fluid intelligence (Gf; abstract problem solving ability) and crystallised intelligence (Gc; acquired knowledge and/or verbal ability), labels proposed by Cattell (1943). While these terms are well-known, he also provided a lesser-known account of their relationship called "investment theory" (Cattell, 1963, 1987). From the perspective of investment theory, Cattell described the formation of Gc as follows: "Crystallized ability consists of discriminatory habits long established in a particular field, originally through the operation of fluid ability, but no longer requiring insightful perception for their successful operation" (1963, p. 178). Stated briefly, Gf is "invested" into Gc over time.

Cattell (1963) argued that the school system played a crucial part in this investment process. Compulsory education in adolescent years provides the basis for a broad Gc factor that emerges from the school curriculum. However, after students graduate from compulsory education the school curriculum would no longer connect Gf and Gc, and the relationship between these constructs would be expected to decay over time. Moreover, because adults have relatively more freedom to choose their own intellectual pursuits, Gc in adulthood might become very diverse, and become more associated with occupational than scholastic knowledge.

Since Cattell's time, several authors have provided accounts that retain the essence of investment theory (e.g. Schweizer & Koch, 2002; Ziegler et al., 2015; Ziegler et al., 2012), with Ackerman's PPIK theory (1996) being the most extensive revision. Ackerman appropriated Cattell's qualification that the investment process would look different in adult than adolescent populations, and provided his PPIK theory to describe this process as it relates to the development of intelligence in adulthood. PPIK defines intelligence as consisting of four related components: intelligence-as-Process, -Personality, -Interest, and -Knowledge. Briefly, Process intelligence relates to Gf, and Knowledge relates to Gc, while Personality and Interest differentiate the broad "interest" component that Cattell (1987) identified but did not define extensively.

More than seven decades have passed since Cattell proposed investment theory, and several studies have assessed its specific predictions. Here we will survey research relating to three such predictions. First, investment theory predicts that general intelligence (*g*) will be more similar to Gf in culturally similar cohorts, and will be more similar to Gc in culturally dissimilar cohorts. This prediction was assessed in studies by Undheim and Gustafsson (1987) and Valentin Kvist and Gustafsson (2008), who found it strongly supported.

Second, investment theory predicts that because of the primacy of Gf in the investment process, Gf will be a leading indicator of the growth of Gc. Ferrer and McArdle (2004) assessed this prediction using measures of broad Gc and academic outcomes, and reported that changes in Gf did not predict changes in Gc, but did predict changes in academic knowledge. This study therefore provides mixed support for investment theory. And third, investment theory predicts that Gf will have higher heritability estimates than Gc. Kan et al. (2013) tested this prediction in a meta-analysis that assessed the heritability of intelligence subtest scores in terms of their cultural load. They reported that subtests with stronger cultural loads had higher heritability estimates—the opposite to what investment theory would predict, and which the authors explained by the effects of genotypic-environmental covariance.

Therefore, tests of predictions that follow from investment theory have reported mixed support, suggesting that the investment process may be even more complex than even Cattell expected. However, the broad idea behind investment theory remains viable, even if specific details require modification.

Investment traits

As noted, the investment theories of Cattell and Ackerman include personality variables that are expected to affect how and where people apply their intellectual abilities. These variables have been called “investment traits” (von Stumm, Hell, et al., 2011). Although several such traits have been identified (von Stumm & Ackerman, 2013), here we highlight two that have been assessed in recent studies: confidence and intellectual curiosity (IC).

Confidence. An important individual difference variable that has the hallmarks of an investment trait is confidence. Confidence has been assessed using either the “self-report” or “online” approaches. While the self-report approach relies on self-report questionnaires in the manner of personality research, the online approach attaches the question “How confident are you that your answer is correct?” to each item in a test administration, and participants respond on a percentage scale. These ratings are then averaged to provide an overall confidence score (Stankov et al., 2015). A recent study has shown that these approaches produce distinct confidence factors: the self-report approaches produces a factor that resembles personality variables, while the online approach produces a factor that resembles ability variables (Burns et al., 2016). However, because the online approach has been assessed more regularly as a predictor of academic achievement (e.g. Stankov et al., 2012), we will use this approach in our study. Furthermore, Stankov (2013) has connected confidence with investment theory: “It seems reasonable to assume that self-beliefs and confidence in particular are the most potent forces that lead to the development of crystallized intelligence as postulated by the investment part of the theory of fluid and crystallized intelligence” (p. 731). Therefore, confidence merits further consideration as an investment trait.

Intellectual curiosity. In recent years, IC has also regularly been investigated as a predictor of academic outcomes. All other things being equal, students who have stronger IC should engage more actively in intellectual pursuits than those with weaker IC, and therefore obtain higher grades. The current evidence for the incremental validity of IC is mixed: while several studies conclude that it shows substantial incremental validity (Chamorro-Premuzic et al., 2006; von Stumm, Hell, et al., 2011), other studies have provided less optimistic conclusions (Powell & Nettelbeck, 2014a; Schroeders et al., 2015). The reason for these different results is uncertain at present.

The Intellect scale

Several measures of IC have been identified in distinct research domains, especially Need for Cognition (Cacioppo & Petty, 1982), Typical Intellectual Engagement (TIE; Goff & Ackerman, 1992), Epistemic Curiosity (Litman, 2008), and the facet Openness to Ideas (OI) within the Openness to Experience factor (Costa & McCrae, 1992b). These measures have been shown to correlate substantially and show only modest discriminant validity (Mussel, 2010; Powell et al., 2016; Woo et al., 2007), indicating that they might be used interchangeably (von Stumm, Hell, et al., 2011). The most recent and theoretically driven attempt to assess IC is the Intellect framework (Mussel, 2013a). This framework defines Intellect along two dimensions, labelled

Process and *Operations*. Process includes two aspects, labelled *Seek* and *Conquer*. While Seek curiosity relates to pursuing new areas of intellectual interest, Conquer curiosity relates to mastering areas of interest once they have been encountered (Mussel, 2013a). Operations relates to three specific activities (Think, Learn, and Create) and draws upon theories that derive from intelligence research (e.g. Carroll, 1993). When combined, the contents of Process and Operations produce six distinct facets. The 24-item scale that accompanies the framework has been shown to relate closely to NFC, TIE, and EC, and thus addresses the same broad construct. However, as none of the other IC scales appear to measure creativity, this is a novel contribution.

Limitations

However, there are several questions within this field that have not been answered clearly, and here we identify three limitations that are worth addressing. First, while Cattell (1963) included academic performance as a form of Gc, he also considered non-achievement variables (including general knowledge) to be forms of Gc. It is not yet clear whether the investment process operates differently for academic outcomes compared to non-academic outcomes. For instance, Conscientiousness has proved to be a consistent predictor of academic achievement (Poropat, 2009, 2014; von Stumm, Hell, et al., 2011), but may not influence investment outside the academic domain. In short, some investment traits may only influence particular investment outcomes. Therefore, a study that assesses Gc in terms of domain-specific general knowledge, instead of academic outcomes, may provide evidence of incremental validity for IC where this has been reported to be lacking (Powell & Nettelbeck, 2014a).

Second, the difference between adolescent and adult populations means that testing investment theory requires a distinct approach for each group—something not all studies have recognised (e.g. Christensen et al., 2013). However, a potential way around this difficulty might be to assess a subset of adults who are exposed to a common curriculum, in parallel with the curriculums of the primary and secondary school systems. Tertiary education provides this opportunity: because students within an academic program are exposed broadly to the same content, the investment process should operate here as it does in cohorts undertaking compulsory education. Moreover, university students acquire domain-specific knowledge rapidly, and provide an excellent chance to see “investment” in action. The ideal students to assess may be those in their final year of their tertiary education, because their longer exposure to course knowledge may provide more opportunity for the influence of investment traits to become apparent.

And third, the place of reading habits in the IC domain remains currently unknown. Among the five main scales that measure IC (TIE, NFC, EC, OI, and Intellect), only TIE measures reading habits (Powell et al., 2016). Moreover, Mussel (2013a) reported TIE’s reading scale to have inadequate psychometric properties, and thus excluded reading from the Intellect framework. Consistent with this finding, Powell et al. (2016) reported that TIE’s reading items associated more strongly with their first-order factor than the general TIE factor, indicating that reading may not fit within this domain. However, it is noteworthy that the TIE scale was published in 1992, well before the Internet became an important source of information. Therefore, an updated reading scale including both traditional and online reading habits, and that is written to align with the Seek and Conquer dimensions of the Intellect scale, may possess better psychometric properties, and fit more closely with the other factors in this domain. It would also provide an opportunity to test the properties of the Intellect scale in an English-speaking sample.

The present study

Considering the limitations listed above, the aim of the present study was to test Cattell's investment theory in an adult university population using a non-achievement measure of Gc, and to assess whether reading habits might be incorporated within the Intellect domain. Cattell's theory suggests that investment traits moderate the relationship between Gf and Gc, and we will therefore assess them using a moderation analysis. The present study tests the following hypotheses:

(1) IC possesses incremental validity above Gf for domain-specific knowledge.

(2) IC moderates the relationship between Gf and domain-specific knowledge.

(3) Confidence possesses incremental validity above Gf for domain-specific knowledge.

(3) Confidence moderates the relationship between Gf and domain-specific knowledge.

(5) Items designed to measure an Intellect–Read factor will load substantially on a general factor from across the Intellect scale.

(6) When assessed in a latent variable model consistent with the Intellect framework, variables Learn and Read will associate at close to unity.

7.3 Method

Participants

Initial participants were 200 third-year psychology students who participated as part of a third-year course, and were informed only that their practical work concerned individual differences in IC and its relationship with achievement. Eleven cases were removed due to lack of consent. Moreover, because investment theory suggests that the investment of Gf into Gc should become stronger over longer time periods, 27 students studying a compressed one-year graduate entry program were excluded from analysis, leaving data for 162 students. Age was reported for 152 students (47 males; age M = 23.53, SD = 7.26). Scores that were deemed to indicate insincere attempts at APM-SF (< 3: n = 3) and Gc (psych) (< 5: n = 2) were also removed. The project received ethics approval, and informed consent was obtained for all students included in the final dataset.

Measures

APM-SF. Raven's Advanced Progressive Matrices-Short Form is a subset of 12 items correlating highly with the original scale, and validated for use with university students with Cronbach's alpha = .73, and test–test reliability = .82 (Bors & Stokes, 1998). It is a widely-accepted measure of Gf. Participants chose one of eight multiple-choice answers. In the present study, Cronbach's alpha was .68.

STW. The Spot-the-Word test is a verbal measure of Gc (Baddeley et al., 1993). Participants are presented with 60 pairs of English words, with each pair containing one real and one made-up word, and participants are asked to identify the real word. It is administered in 5 minutes, and in the present study its Cronbach's alpha was .90.

Gc (psych). We developed a domain-specific measure of psychology knowledge specifically for this study. Rather than composing original questionnaire items, we used items from the Graduate Record Examinations (GRE) Psychology practice test. In the United States, GRE tests are used to assess suitability for graduate programs, and these tests (including practice tests) are designed to measure knowledge gained from undergraduate programs.

However, given the length of the full practice test (approximately 205 items) and differences between psychology programs in the US and elsewhere, we selected a subset of items to be administered. The first author selected an initial pool of 60 items, from which all three authors chose 20 items that they judged best spanned the content of our university's psychology program. Our aim was to produce a measure of psychology general knowledge that overlapped with course content, but was distinct from course grades. Participants selected one of five possible multiple-choice answers. Cronbach's alpha for this measure was .48

Confidence. Measures of confidence were attached to the measure of Gc (psych) using the "online" approach (Stankov et al., 2015). Participants were asked "How confident are you that your answer is correct?" and responded on a scale of 0–100% with anchors at 10% intervals (Stankov et al., 2012). Item-level scores for each scale were averaged across all scale items to produce a measure of confidence for each participant.

Intellect. Mussel's (2013a) Intellect scale is composed of 24 items that assess personality traits related to intellectual achievement. Participants responded to each item on a 6-point Likert scale (0 = "never" to 6 = "always"). In the present study, Cronbach's alpha was .96.

Intellect–Read. To develop a scale that assesses reading habits related to intellectual achievements, we composed 24 questionnaire items from which to select eight to form a reading factor. Because the Intellect Scale assesses Seek and Conquer processes, we worded 12 items to align with each process. Moreover, because both books and the Internet are now significant sources of information, each group of 12 included six items assessing reading books and six assessed online reading. We conducted a principal component analysis on each group of six items, and retained the two items that loaded most strongly on the first principal component. These eight items formed the Intellect–Read scale, and are listed Table 1. Cronbach's alpha was .93, which could not be improved by removing any items. Moreover, pooling these items with those from the full Intellect scale produced a Cronbach's alpha of .97, which could not be improved by removing any items.

Procedure

Participants completed the APM-SF, the Gc (psych), and the STW test in a psychology lecture under test conditions, with time constraints of 15, 20, and 5 minutes respectively. Subsequently, the remaining variables were collected online using SurveyMonkey. In order of administration, this administration included: (1) information and consent; (2) ID, age, sex, and degree major; (3) a measure of five-factor model personality (not analysed further); (4) the Need for Cognition scale (not analysed further); (5) the Intellect scale and reading items from which would be reduced to compose the Intellect–Read scale; and (5) contact details for the study.

Statistical analyses

Statistical analyses were conducted in SPSS version 24, except for the Schmid-Leiman transformation conducted in *R* (R Development Core Team, 2014).

7.4 Results

Descriptive statistics and correlations

Descriptive statistics for all analysed variables are presented in Table 7.1. The average score for APM-SF appeared to be slightly higher than that obtained for students in the same class the previous year (*M* = 7.40), possibly because this year's administration was in-class under test conditions rather than online. The average score for STW appeared to be slightly lower than that obtained in a validation study (*M* = 53.00), possibly because the validation study involved participants of high verbal ability (Baddeley et al., 1993).

Table 7.1
Variable means and standard deviations, range of scores and internal consistency (alpha)

Variable	*n*	*M*	*SD*	Range		Alpha
				Potential	Actual	
APM-SF	140	7.89	2.29	0–12	3–12	.68
STW	144	43.09	9.22	0–60	18–57	.90
Gc (psych)	142	12.66	2.44	0–20	6–20	.48
Confidence	143	52.29	14.79	0–100	9.50–88.42	N/A
Intellect	152	86.19	20.6	24–144	26–141	.96
Intellect–Read	152	27.45	9.14	8–48	8–48	.93

Note: APM-SF = Advanced Progressive Matrices–Short Form; STW = Spot-the-Word test; Gc (psych) = crystallised intelligence psychology knowledge.

The Gc (psych) measure was developed for this study, so there is no available comparison data. Its purpose was to discriminate between students' levels of psychology general knowledge, and the mean (12.66), standard deviation (2.44) and range (6-20) indicated that it succeeded in this regard. However, its alpha reliability of .48 was unacceptable, indicating that the items do not assess a single dimension—

probably because they spanned several distinct domains of psychology knowledge. Removing five items improved the alpha to .52, but it could not be improved further. However, removing these five items attenuated the correlations between Gc (psych) and other variables, and did not improve its predictive validity in the regression models. Moreover, because the improved alpha of .52 was still unacceptable, we retained all 20 items for Gc (psych) in the final analyses. Confidence ratings were attached to Gc (psych) items, and confidence ratings suggested an average score of 10.5/20 compared with the obtained average of 12.7/20, suggesting underconfidence in this sample.

Intellect scores obtained here are not comparable to the validation studies of Mussel (2013a) because of different scale anchors, but the alphas in the present study (.96) and in the validation studies (.93 and .94) were comparable and very high. As reported below, Cronbach's alpha for Intellect–Read (.93) was very high for an 8-item scale, and the overall alpha when from 32 items pooled from the Intellect and Intellect–Read scales was extremely high at .97.

Sex differences were tested for all variables. Male scores for Intellect (M = 92.51) were higher than female scores (M = 83.36; t (150) = 2.58, p = .01) with a medium effect size (d = .46). This is consistent with our findings on other measures of IC in a similar cohort, where males reported significantly higher levels of Need for Cognition than females (Powell et al., 2016). No other sex differences were obtained in the present study.

Correlations between variables are presented in Table 7.2. A moderate correlation was obtained between APM–SF and STW, consistent with many studies that show overlap between measures of Gf and Gc (e.g. Goff & Ackerman, 1992). The moderate correlation between APM–SF and Gc (psych) could be explained by investment of Gf into Gc over time, or by the fact that those with higher Gf are more capable in test situations. Unexpectedly, Intellect and Intellect–Read did not correlate significantly with APM–SF, but did show weak-to-moderate correlations with STW, indicating a more substantial overlap with Gc than with Gf A strong correlation was obtained between Gc (psych) and confidence, probably because confidence ratings were yoked to this test. Finally, a strong correlation was obtained between Intellect and Intellect–Read, which is expected given the content of these scales. No other correlations were statistically significant.

Table 7.2
Pearson correlations between variables

Variable	STW	Gc (psych)	Confidence	Intellect	Intellect–Read
APM–SF	.23**	.25**	.12	.02	.03
STW		.12	.11	.17*	.19*
Gc (psych)			.48**	.00	.11
Confidence				.03	.03
Intellect					.83**

Note: APM–SF = Advanced Progressive Matrices–Short Form; STW = Spot-the-Word test; Gc (psych) = crystallised intelligence psychology knowledge.
* $p < .05$, 2-tailed.
** $p < .01$, 2-tailed.

Regression models

Stepwise hierarchical multiple regression was used to test hypotheses 1–4 in this study, where the outcome variable was Gc (psych). Because of the possibility of multicollinearity with the interaction terms, all predictor variables analysed in the regression models were transformed into z-scores.

Assumptions. Assumptions underlying multiple regression were tested for each analysis. Using the transformed variables, no violations of multicollinearity were found from the correlations of predictors with one another ($r > .7$) or considering Tolerance and VIF statistics. Moreover, scatterplots revealed no violations of normality, linearity, or homoscedasticity, indicating the that the data were suitable for regression analysis.

Incremental validity and moderation. To assess the incremental validity of IC and Confidence over Gf for predicting domain-specific knowledge we used stepwise hierarchical multiple regression—reported in Table 7.3. Models 1–3 assessed Intellect as a predictor of Gc (psych). Step 1 was the base model and included only APM–SF. Step 2 added Intellect, which explained no significant additional variance. Step 3 added an interaction term between APM–SF and Intellect, which explained no significant additional variance. Therefore, IC did not possess incremental validity over Gf for predicting domain-specific knowledge, and did not moderate the relationship between Gf and domain-specific knowledge. These results do not support hypotheses 1 or 2.

Next, models 4–6 assessed Confidence as a predictor of Gc (psych). Step 1 was the base model and included only APM–SF. Step 2 added Confidence which explained significant and substantial incremental variance above step 1. Step 3 added an interaction term between APM–SF and Confidence, which explained no significant additional variance. Therefore, IC possessed incremental validity over Gf for predicting domain-specific knowledge, but did not moderate the relationship between Gf and domain-specific knowledge. These results support hypothesis 3 but not hypothesis 4.

Table 7.3

Regression model comparisons for predicting Gc (psych)

	Model 1 (base)	Model 2	Model 3	Model 4 (base)	Model 5	Model 6
	$F[1, 128] = 11.13$**	$F[2, 127] = 5.57$**	$F[3, 126] = 3.71$*	$F[1, 135] = 9.06$**	$F[2, 134] = 24.99$**	$F[3, 133] = 16.55$**
	$R^2 = .08$	$R^2 = .08$	$R^2 = .29$	$R^2 = .06$	$R^2 = .27$	$R^2 = .27$
		R^2 change = .00	R^2 change = .01		R^2 change = .21**	R^2 change = .00
Predictor	Beta	Beta	Beta	Beta	Beta	Beta
APM–SF	.28**	.28**	.29**	.25**	.19*	.19*
Intellect	-	.03	.02	-	-	-
APM–SF x Intellect	-	-	-.03	-	-	-
Confidence	-	-	-	-	.46**	.46**
APM–SF x Confidence	-	-	-	-	-	.02

Notes. APM–SF = Raven's Advance Progressive Matrices (Short Form).

* $p < .05$, 2-tailed.

** $p < .01$, 2-tailed.

Analysis of the Intellect–Read scale

To assess the Intellect–Read scale, we decided first to conduct an exploratory factor analysis on the items pooled from the Intellect scale (24 items) and the Intellect–Read scale (eight items). We first assessed the suitability of the scale items for component analysis, which was confirmed by a KMO value of .94 and a significant result for Bartlett's test of sphericity. To determine the number of factors or components to extract, we used the scree test (Cattell, 1966) and Horn's Parallel analysis (Horn, 1965). Using Principal Component Analysis, the scree plot showed a single, domain component, and little-to-no evidence of more components. Parallel analysis using a 95th percentile criterion suggested a root value cutoff of 1.94 for a second component, which exceeded the root value of 1.87 in the dataset. When considered alongside the Cronbach's alpha of .97 for all 32 items, this analysis strongly suggests the presence of a single factor that overarches this domain, which lead us to extract a single principal component. The component matrix is reported in Table 7.4. The Intellect–Read items are spread throughout component loadings, and appear to be indistinct from the Intellect items. This analysis supports hypothesis 5.

Table 7.4

First principal component loadings for Intellect and Intellect–Read items

Scale and Item number	Item	Loading
Intellect 15	I take the time to investigate practical solutions until I have discovered the underlying theory.	.83
Intellect 20	Once I have become familiar with a new subject, I cannot rest until I have understood it.	.82
Intellect 4	I enjoy occupying myself with theories that are new to me.	.80
Intellect 16	Once I get to know a new theory, I cannot rest until I have understood it fully.	.80
Intellect 8	I find it fun getting familiar with new subjects.	.80
Intellect–Read 4	I become absorbed reading about new theories online.	.79
Intellect–Read 2	I become absorbed reading books about new theories.	.78
Intellect–Read 5	I spend a lot of time reading books to learn everything I can about a subject.	.78
Intellect–Read 6	I read books in order to conquer topics that are important to me.	.77
Intellect 17	I take a lot of time so as to gain in-depth understanding of a new process.	.76
Intellect–Read 7	I often surf the net, reading everything I can about a subject.	.76
Intellect 6	I enjoy learning about subjects that I'm not familiar with.	.75
Intellect 3	Regarding practical problems, I'm also interested in the underlying theory.	.75
Intellect 21	I give a lot of time to developing new ideas until they are fully developed.	.74
Intellect 18	I concentrate on new subjects for as long as it takes to learn everything about them.	.74
Intellect–Read 3	I can surf the net for hours, reading about new discoveries.	.72

Intellect 7	I find it fascinating learning new things.	.72
Intellect 24	When I'm developing something new, I can't rest until it's completed.	.72
Intellect–Read 1	I enjoy reading books on subjects that are new to me.	.71
Intellect 19	If there is something that I don't know or have not understood, I spend a lot of time on it.	.70
Intellect 11	I enjoy developing new concepts.	.69
Intellect 22	I persevere with the development of new products until they are ready.	.69
Intellect 9	I like being part of developing new ideas.	.69
Intellect 12	I enjoy developing something new.	.68
Intellect–Read 8	I spend a lot of time reading online about particular subjects.	.68
Intellect 1	I enjoy solving complex problems.	.68
Intellect 13	I take time thinking about complex problems until I have found a solution.	.65
Intellect 5	I would like to learn new ways of doing things.	.64
Intellect 2	I enjoy puzzling and thinking things out.	.64
Intellect 23	When I am working on a new concept, I make every effort to see it through to an end.	.62
Intellect 10	I enjoy developing new products.	.61
Intellect 14	I am able to think about things in a lengthy, focused way.	.59

To assess the sixth hypothesis, we produced two latent variables models informed by Intellect framework. Model 1 was equivalent to Model 1 reported by Mussel (2013a, pp. 893-4)—the model with the closest fit among those he compared, and which included the two processes and three operations. Our Model 2 also included two processes, but added Read as a fourth operation. This allowed us to compare the fit of the models without and with the Read operation, and also to compare our results directly with those of Mussel (2013a). Fit statistics are reported in Table 7.5, and Models 1 and 2 are presented in Figures 7.1 and 7.2, respectively.

Table 7.5
Results from confirmatory factor analysis

Model	χ^2	*df*	χ^2 / *df*	CFI	RMSEA
M1	678	262	2.59	.84	.10
M2	1203	477	2.52	.82	.10

Note. n = 152; M1 = model without Read scale (equivalent to M4 in Mussel [2013], p. 894); M2 = model with Read scale; df = degrees of freedom; CFI = comparative fit index; RMSEA = root-mean-square error of approximation.

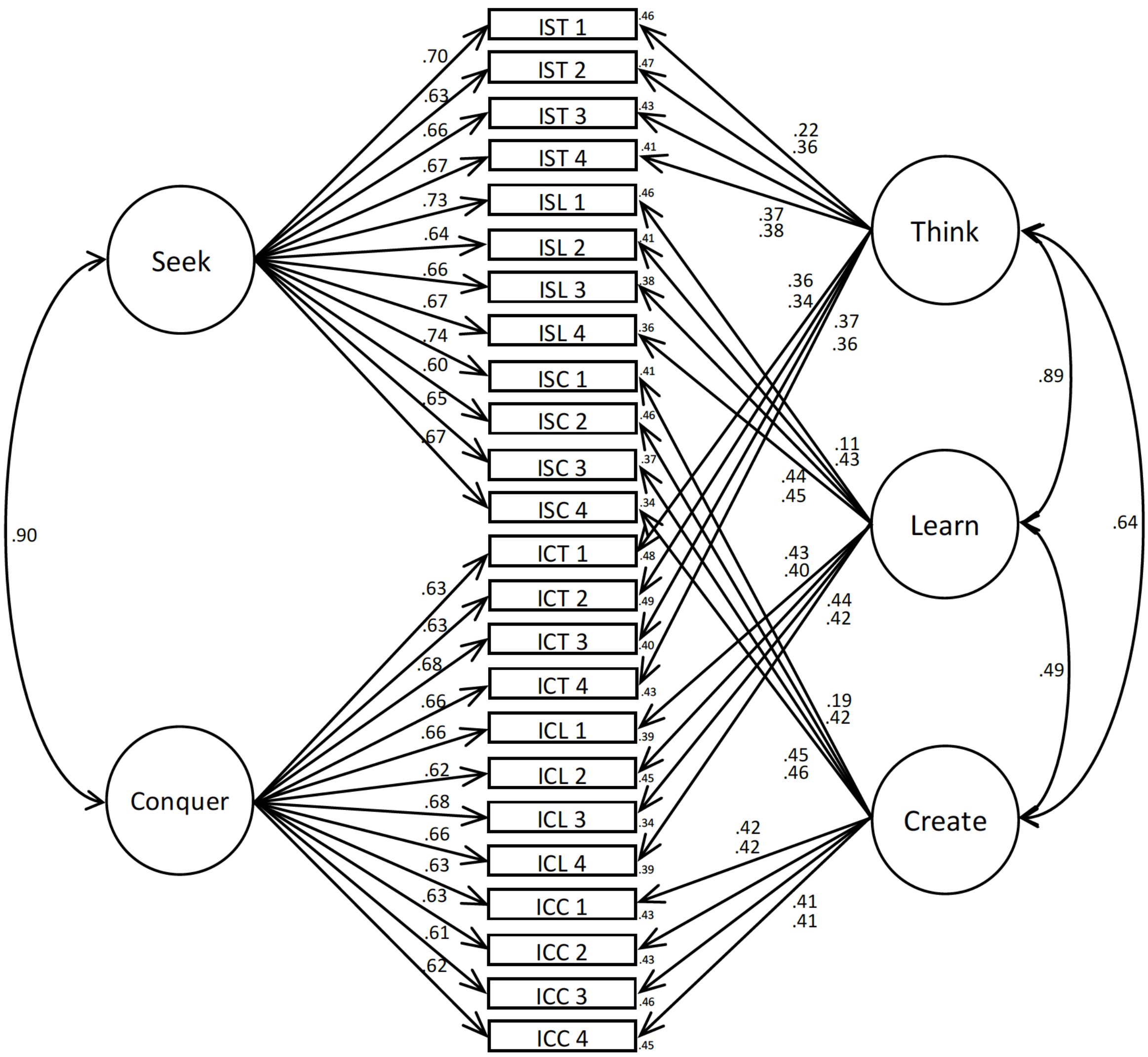
The main difference apparent between Model 1 in both datasets was that the relationship between Seek and Conquer processes was stronger in our data (.90) compared with Mussel's (.44).[14] Possibly because of this difference, this model attributed more variance in our data to the processes, whereas it attributed more variance in Mussel's data to the operations. These different results may have been due to different characteristics in the sample population.

[14] Given the strong overlap between the processes in our data, we also assessed a bi-factor model (with a single process factor), but this did not provide a superior fit.

Neither model showed evidence of close fit according to conventional standards (Hu & Bentler, 1999). Although fit statistics were close for the two models, CFI was slightly better for M1. Moreover, as is apparent from figure 2, the correlation between Read and Learn operations was very strong (.93), indicating that these items measure virtually the same latent construct. Therefore, in the interests of theoretical and practical parsimony, the original model (M1) is preferred. These results support hypothesis 6.

Figure 7.1

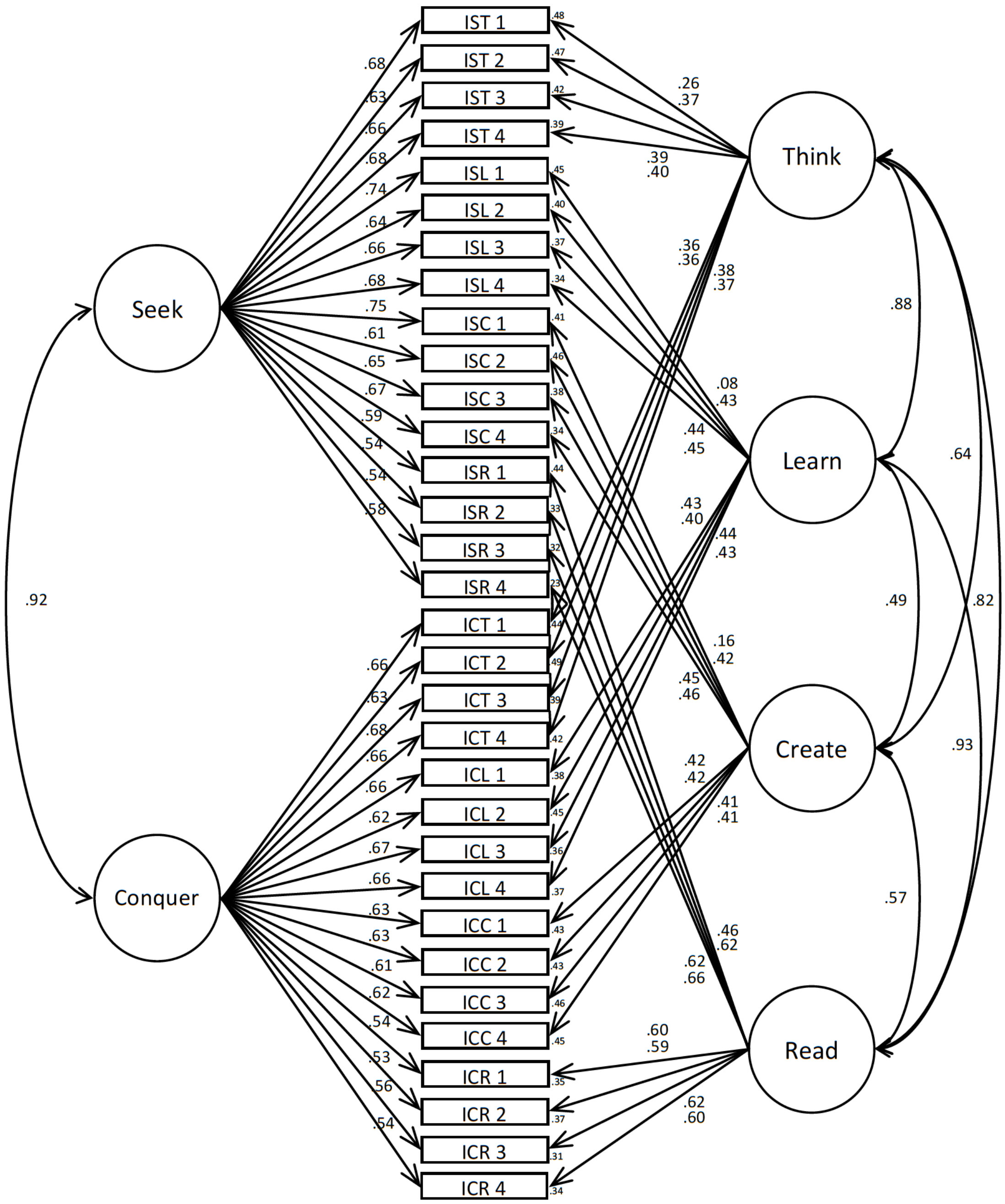
Standardised estimates for Model 1



Note. Figure displays standardised estimates from CFA Model 1 (reported in Table 5). Item codes follow the pattern: scale (I = Intellect), Process (S = Seek, C = Conquer), Operation (T = Think, L = Learn, C = Create), item number. Thus, IST 1 = Intellect Seek Think item 1. Loadings and covariances are next to each path, and residual variances are in small type next to each item.

Figure 7.2

Standardised estimates for Model 2



Note. Figure displays standardised estimates from the CFA Model 2 (reported in Table 5). Item codes follow the pattern: scale (I = Intellect), Process (S = Seek, C = Conquer), Operation (T = Think, L = Learn, C = Create, R = Read), item number. Thus, ICR 4 = Intellect Seek Read item 4. Loadings and covariances are next to each path, and residual variances are in small type next to each item.

7.5 Discussion

We will discuss the significance of these results in four sections: (1) investment theory, (2) the Intellect framework, (3) limitations, and (4) future directions.

Investment theory. The present study was novel because it directly compared the predictive power of two distinct investment traits, IC and confidence. Despite their associations with investment theory, the lines of enquiry for each of these variables have remained separate, as we know of no other study that has compared them. Only confidence explained incremental variance in domain-specific knowledge, and this is consistent with Stankov's suggestion that measures of self-belief generally, and confidence in particular, are the "most potent" forces in the investment process (2013, p. 731).

These results add to the growing body of evidence that the predictive power of IC may differ by the population being assessed, and provide further evidence that confidence is an important predictor of learning outcomes above the influence of intelligence. Moreover, the absence of interaction effects indicates that the contributions of intellectual ability and investment traits are independent of one another. However, these findings and their potential implications for investment theory remain speculations because of several limitations in this study—especially the poor reliability of the scale measuring Gc (psych), discussed below.

The Intellect framework. This study is also relevant to the Intellect framework proposed by Mussel (2013a) and other approaches to measuring IC. Although TIE includes items assessing reading habits, no other scale measuring IC does so. Practically, the very high reliability indicates that the English translations of the original German items measure a unitary construct in this Australian population.

Furthermore, these findings indicate that readings habits could be added to this scale, as reliability improved slightly with their inclusion (Cronbach's alpha increased from .96 to .97). Theoretically, however, this addition may not advance the Intellect domain very far, as this scale already includes the operation Learn—an activity that surely includes reading habits. Moreover, if the reading items are virtually indistinguishable from the existing items, there is no clear benefit from adding them. Thus, we suggest that the Intellect scale already captures essence of reading habits that relate to IC, and does not need to include this activity formally.

Limitations. We will discuss three significant limitations with the present study. A first, major limitation was the poor reliability of the scale designed to measure Gc (psych), indicating that this scale does not assess a single, broad factor of psychology knowledge. This might have been due to the lack of a fully-fledged validation process, where many items are administered initially, and reduced subsequently based on factor loadings. It may also indicate that psychology knowledge in psychology students is composed of relatively discrete domains, and that assessing investment theory as it relates to domain-specific knowledge would require a still narrower sampling of knowledge.

A second limitation relates to the measure of domain-specific knowledge itself. Because we selected questionnaire items that overlapped with course content, it could be argued that what we have measured is in fact a variable that captures academic achievement, albeit loosely. Although we have not reported the FFM variables that we measured as part of this study, the correlation between Conscientiousness and Gc (psych) was negligible and non-significant (r = .02, p = .83). Given the robust associations reported between Conscientiousness and course outcomes (e.g. Schuler et al., 2007), this lack of relationship suggests that our measure of Gc (psych) is not simply a proxy for academic achievement. However, we could have tested this idea more effectively had we assessed university grades in this study.

A third limitation of the present study was its correlational design. Investment theory suggests that the Gf is invested in Gc over time, so the present study at best could have provided results that are consistent with investment theory without providing definitive proof. A stronger test would involve a longitudinal study of change in the variables, ideally from the beginning to the end of an academic program.

Future directions. This study suggests several possible future directions. First, it would be helpful to replicate the approach we have advocated here, but with a more robustly-developed measure of domain-specific knowledge. This would likely include a two-stage process, where (1) a large initial pool of questions is used to derive a scale that measures domain-specific knowledge, and (2) subsequently this scale is used in a study like the present study. This would help to assess whether our finding that confidence predicted more variance in domain-specific knowledge than IC is robust, or is due to this scale's poor reliability.

Second, future studies might re-assess the claim that IC is the "third pillar" of academic performance alongside intelligence and Conscientiousness (von Stumm, Hell, et al., 2011). Although several studies have reported that IC possesses incremental validity when predicting academic outcomes (Chamorro-Premuzic et al., 2006; Furnham et al., 2009; von Stumm, Hell, et al., 2011), other studies have been less optimistic (Powell & Nettelbeck, 2014a; Schroeders et al., 2015). The explanation for these different results is currently uncertain. We note that the meta-analysis of von

Stumm, Hell, et al. (2011) used TIE as the measure of IC, but that the meta-analytic correlations were based on very few studies, which calls their robustness into question. Moreover, von Stumm and Ackerman (2013) report associations between several investment traits and investment outcomes, and indicates that there are substantially more studies associating NFC with academic performance than there are for TIE. Given the strong association between these constructs (Powell et al., 2016), it may be enlightening to substitute NFC for TIE and assess this question again with a larger dataset.

Third, the present study indicates that Confidence deserves further attention as a predictor of investment outcomes. To our knowledge, this is the only study that has compared directly IC and Confidence as they relate to learning outcomes. Although Confidence possessed substantial incremental validity above intelligence, this finding should be replicated for the reasons noted above. Moreover, although few studies associate Confidence with intelligence, personality variables, and academic performance, more such studies might permit the approach of von Stumm, Hell, et al. (2011) to be used for Confidence rather than IC. If any broad conclusion can be drawn from the present study, it is that Confidence is more potent than IC for predicting learning outcomes.

Statement of Authorship

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Contribution to the Paper	Statistical analyses, writing manuscript.		
Overall percentage (%)	80%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	11/4/17

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);
ii. permission is granted for the candidate in include the publication in the thesis; and
iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

Name of Co-Author	Nicholas R. Burns		
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Contribution to the Paper	Principal supervision, manuscript proofreading.		
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8 Study 4: The Unsteady Pillar—A Critique of von Stumm, Hell, and Chamorro-Premuzic (2011)

8.1 Abstract

"The Hungry Mind: Intellectual Curiosity is the Third Pillar of Academic Performance" (von Stumm, Hell, & Chamorro-Premuzic, 2011) has been an influential study since its publication. However, here we challenge its major conclusion, and seek to clarify what we know—and do not know—about intellectual curiosity as a predictor of academic performance.

8.2 Introduction

In the field of personality predictors of academic performance (AP), an influential study in recent years has been von Stumm, Hell, and Chamorro-Premuzic (2011). Based on a path model using meta-analytic coefficients, the authors argued that intellectual curiosity (IC) has been established as the "third pillar" of academic performance, together with general intelligence (*g*) and Conscientiousness. Although we do not dispute the associations presented between intelligence and AP, and between Conscientiousness and AP, we are not persuaded that the relationship between IC and AP has been demonstrated sufficiently. In the present study, we critique the approach taken by the authors, and provide what we think are more adequate interpretations of the research available.

The authors focused on Typical Intellectual Engagement (Goff & Ackerman, 1992) as a marker of IC. While acknowledging that TIE is a valid measure of IC, we suggest that the evidence base at the time of the publication was insufficient to support their conclusion. Moreover, we argue that the true relationship between TIE and AP may be substantially weaker than is suggested by the path coefficient reported by von Stumm, Hell, et al. (2011). Our critique comprises four parts: *Typical Intellectual Engagement and Academic Performance*; *the Incremental Validity of Typical Intellectual Engagement; Need for Cognition and Academic Performance*; and *Alternative Path Models*.

8.3 Typical Intellectual Engagement and Academic Performance

A crucial component of the argument advanced by von Stumm, Hell, et al. (2011) involved calculating the meta-analytic correlation between TIE and academic performance (AP). The authors provided an estimate of $\rho = .328$ between TIE and AP, with a 95% confidence interval of .17 to .49 using a random effects model. This interval width is clearly due to the small number of studies (*k* = 4) and overall participants (*N* = 608).

However, the calculation of the TIE–AP correlation appears to have been based on an error. Although the studies were listed as *k* = 4, two of the correlations were drawn from the same study (Wilhelm et al., 2003). Given that participant numbers for both studies were identical (*n* = 183), these correlations appear to have been grades for different subjects using the same students. A more suitable method would have been to average correlations between TIE and the grades (-.26 for humanities GPA and -.37 GPA for Science GPA)[15], resulting in *r* = -.32, and reducing the overall number of studies (*k* = 3) and participants (*N* = 425).

Indeed, this approach was used in the subsequent meta-analysis by von Stumm and Ackerman (2013), who reviewed correlations available between TIE and AP. Here, the same three studies were used to calculate the meta-analytic correlation, and the corrected correlation reported was ρ = .29 (reduced from .33), with confidence intervals .05 to .50 (random effects model). Therefore, although the relationship between TIE and AP is likely positive, the range of possible values is very wide. Using this corrected correlation changes the values in the path model of von Stumm, Hell, et al. (2011), weakening the path between TIE and AP in the final model. Moreover, given the very limited number of studies available, this correlation will be influenced by any correlations reported subsequently.

[15] The negative correlations were due to the German system of assessment, where lower numbers represent better grades. These were reversed for the meta-analysis.

The three correlations used by von Stumm and Ackerman (2013) to estimate the relationship between TIE and AP varied considerably—r = .04 (Goff & Ackerman, 1992), r = -.32 (Wilhelm et al., 2003), and r = .36 (Chamorro-Premuzic et al., 2006)—as have the correlations reported subsequently. In our research, we have obtained zero-order correlations of r = .35 (Powell & Nettelbeck, 2014a) and .16 (Powell, Nettelbeck, & Burns, 2017) between TIE and AP, while Schroeders et al. (2015) reported r = .27 between TIE and mathematics achievement in German secondary students. Although two of the values were not statistically significant (Goff & Ackerman, 1992; Powell, Nettelbeck, & Burns, 2016), these observations suggest that the correlation between TIE and AP is positive but varies considerably in magnitude from study-to-study. As we demonstrate below, gauging the strength of this correlation accurately is crucial to evaluating von Stumm et al.'s (2011) conclusion.

8.4 The Incremental Validity of Typical Intellectual Engagement

The aim of von Stumm, Hell, et al. (2011) appeared to be to demonstrate the incremental validity of TIE for AP beyond known major predictors, via meta-analysis. We are aware of four studies that have attempted this; surveying them highlights the strengths and weaknesses of the meta-analytic approach.

The strongest evidence comes from Chamorro-Premuzic et al. (2006), who obtained substantial incremental validity for TIE beyond variance explained by intelligence and Five Factor Model (FFM; Costa & McCrae, 1992a) personality measures in 104 university psychology students (range 3–9% depending on the method of assessment). However, the correlation between TIE and Openness to Experience in this study was low (r = .24) compared with other studies (usually around .6), the sample size was small, and we are not aware of another study replicating this result.

In a sample of 7,207 German secondary students, Schroeders et al. (2015) reported substantial zero-order relationships between TIE and AP for mathematics and science subjects. However, after controlling for fluid intelligence, gender, migration background, SES, and subject-specific interest, TIE showed only limited incremental validity (range 0.5–1.8% across academic subjects). Notably, this study did not assess other personality variables (such as Conscientiousness)—doing so would likely have reduced the incremental validity of TIE further. The authors concluded that the evidence for incremental validity for TIE was marginal for mathematics and science subjects, but noted that it may be more substantial for humanities-type subjects.

In our own research, using first-year psychology students (Powell & Nettelbeck, 2014a), we reported a correlation of $r = .35$ between self-report AP (university entrance scores) and TIE measured about six months later. However, we found little evidence of incremental validity for TIE beyond fluid intelligence and Conscientiousness (about 1.8%), and no significant incremental validity for other IC measures (Need for Cognition, Epistemic Curiosity, and the Intellect scale from the International Personality Item Pool). In another study using third-year psychology students (Powell et al., 2017), we obtained a non-significant correlation of $r = .16$ between TIE and AP, measured by average percentage grades across second and third-year subjects. However, we found no incremental validity whatsoever for TIE beyond variance explained by fluid (Gf) and crystallised (Gc) intelligence, and FFM personality.

Therefore, despite the apparent similarity between these approaches, the extent of incremental validity for TIE has varied substantially. The strength of an approach such as von Stumm et al.'s (2011) is the same as for any meta-analyses: it allows a more robust estimate of the relationships between variables where those relationships can be affected by the context in which they are measured. However, this is also the weakness of such an approach: meta-analysis is not intended to accommodate contextual issues, and conclusions do not aim to explain variation between the studies they integrate. Given the inconsistent nature of evidence reviewed here, we suspect that this may be the case for the incremental validity of TIE.

8.5 Need for Cognition and Academic Performance

As several authors have observed, TIE is one of many scales measuring IC (e.g. Mussel, 2010; von Stumm & Ackerman, 2013; von Stumm, Hell, et al., 2011; Woo et al., 2007). Another measure is Need for Cognition (NFC; Cacioppo & Petty, 1982), which has been shown to correlate very strongly with TIE. Our own studies have found correlations of r = .86 (Powell et al., 2016) and .81 (Powell et al., 2017) between these measures, and Mussel (2010, 2013a) has reported correlations of .75 and .73, respectively. Woo et al. (2007) obtained r = .78, and concluded that these scales assess essentially the same construct. Moreover, studies that have measured both scales report similar patterns of association between these measures and a number of outcome variables (e.g. Mussel, 2010; Woo et al., 2007).

Our research on AP has found near-identical correlations between AP and both TIE and NFC: Powell and Nettelbeck (2014a) reported correlations for AP with TIE and NFC of r = .35 and .33 respectively, and Powell et al. (2017) reported correlations of .16 in both cases. The magnitude of their relationship is similar to different measures assessing the same FFM construct, and their principal difference is that TIE includes reading habits while NFC does not (Powell et al., 2016). All things considered, however, we concur with the assessment of von Stumm, Hell, et al. (2011):

> That is, measures of intellectual investment and curiosity have matching conceptual roots, include semantically identical items, and share criteria validity for academic performance and intelligence; therefore, they appear to assess the same trait dimension, and corresponding scales might be interchangeably used. (p. 577)

Furthermore, the review by von Stumm and Ackerman (2013) indicated that NFC has received more extensive research than TIE as a predictor of AP. They identified 12 studies (*N* = 2,998) correlating NFC with AP, but only three (*N* = 425) on TIE—and the vast majority of the NFC studies were available in the few years before the publication of von Stumm, Hell, et al. (2011). Their review also indicated that more correlations are available between NFC and Gc: they reported 16 (*N* = 5,164) correlations between NFC and Gc, but only seven (*N* = 1,487) between TIE and Gc. Given this substantial overlap, and that meta-analyses generally are stronger when they include more correlations, the decision of von Stumm, Hell, et al. (2011) to use TIE instead of NFC is questionable. We will return to this point shortly.

8.6 Alternative Path Models

Given the above considerations, we have re-run the path models presented by von Stumm, Hell, et al. (2011), but substituted alternative values for correlations involving TIE and AP. This exercise demonstrates that ostensibly minor changes can induce substantial variation in such models, and emphasises the tentative nature of conclusions based on limited evidence. Table 8.1 presents the correlations between the all variables, reproduced from von Stumm, Hell, et al. (2011). We began by using these values and successfully reproduced their final path model, presented in Figure 8.1.

Table 8.1

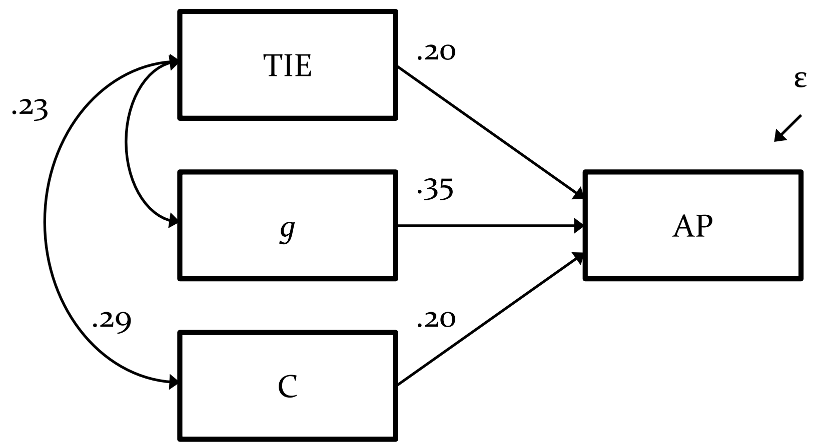
Meta-analytic correlation matrix from von Stumm, Hell, et al. (2011)

Variable	*g*	AP	C	TIE
General intelligence (*g*)	-			
Academic performance (AP)	.39	-		
Conscientiousness (C)	-.04	.24[a]	-	
Typical Intellectual Engagement (TIE)	.22	.33	.28	-

Note. Reported sample sizes ranged from N = 608 [actual 425] to N = 28,471 [actual 68,063]. [a] von Stumm, Hell, et al. (2011) reported this correlation inconsistently as ρ = .24 (p. 581) and .23 (p. 584), but appear to have used .24 in the final model. The original study of Poropat (2009, p. 329) provided estimates of ρ = .24 (N = 68,063) for all academic levels, and .23 (N = 32,887) for tertiary students.

Figure 8.1

Path model from von Stumm, Hell, and Chamorro-Premuzic (2011)

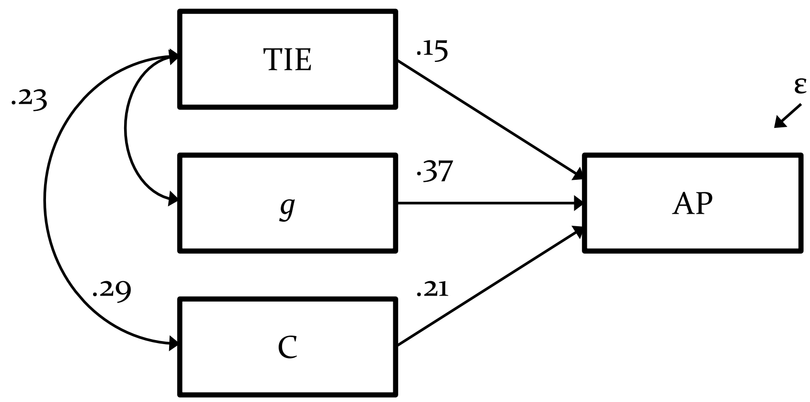


TIE = Typical Intellectual Engagement; *g* = general intelligence; C = Conscientiousness; AP = academic performance.

For the second model, we used the corrected correlation between TIE and AP (ρ = .29, random effects) provided by von Stumm and Ackerman (2013). This resulted in the modified path model presented in Figure 8.2. The broad pattern of relationships was similar for the two models, but the strength of the direct path from TIE to AP was reduced from the estimate in the initial model. Using this model to estimate these variables as predictors of AP, we would conclude that intelligence is most important predictor, followed by Conscientiousness, followed by TIE.

Figure 8.2

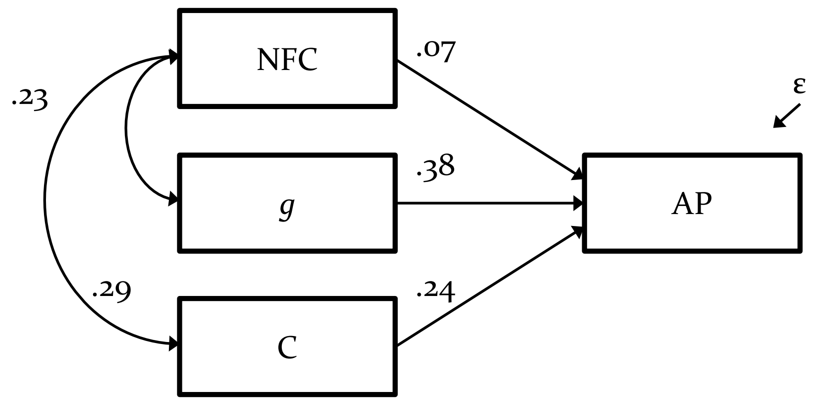
Alternative path model using corrected value (ρ = .29) for TIE



TIE = Typical Intellectual Engagement; *g* = general intelligence; C = Conscientiousness; AP = academic performance.

However, we suggest that the most informative approach appears in Figure 3. In our third model, we substituted the correlation provided by von Stumm and Ackerman (2013) between NFC and AP, reported as ρ = .22 (random effects). We noted, however, that this figure was overstated due to several clerical errors, especially: (1) the correlation between NFC and AP obtained by Taube (1995/1997) was reported as r = .30, while the original study reports .16; and (2) the correlation between NFC and AP obtained by Ku and Ho (2010) was reported as r = .11, while the original study reports -.14. Although we estimated that these corrections reduced the correlation between NFC and AP to approximately ρ = .20 (95% CI .13–.27), we lacked details on which random effects model von Stumm and Ackerman (2013), and therefore retained their original value of ρ = .22. Using this higher estimate served to *overstate* the unique contribution of NFC as a predictor of AP in our final model.

Figure 8.3
Alternative path model substituting NFC value (ρ = .22) for TIE value



NFC = Need for Cognition; g = general intelligence; C = Conscientiousness; AP = academic performance.

This path model changed substantially different the models presented in Figures 1 and 2. Although intelligence and Conscientiousness remained substantial predictors, the distinct contribution of NFC became marginal. When the strengths of the paths from predictors to AP were re-calculated as percentages of the total explained variance for AP, general intelligence was the most powerful predictor (55%), Conscientiousness was substantial but less powerful (35%), while NFC predicted very modest (10%) variance in AP. In short, assuming near-equivalence between NFC and

TIE, this lead to an appreciably different conclusion about TIE as a predictor of AP than von Stumm, Hell, et al. (2011) provided.[16]

8.7 Discussion

Let us be clear: we are *not* arguing that we can simply substitute the value for NFC for the value of TIE and thereby discount the conclusion of von Stumm, Hell, et al. (2011). Our position is that, given strong correlations between NFC and TIE, and the limited research correlating TIE with AP, we think that an accurate assessment of the relationship between TIE and AP is currently very difficult to make. However, if this correlation lies at the lower end of its probable range—and the association of NFC with AP suggests that it may be closer to $r = .2$ than .3—then the conclusion that IC is the "third pillar of academic performance" becomes untenable.

Meta-analyses have an important place in the hierarchy of research, for the obvious reason that their conclusions are based upon a larger body of research than provided by individual studies. However, they cannot be stronger than the evidence base they synthesise. Although we have not specifically taken issue with the general approach of von Stumm, Hell, et al. (2011), we think that their conclusion was premature—at least in the case of TIE. The more extensive research on NFC make it a stronger candidate for such an analysis, although our observations suggest that it may account for less variance in AP than does Conscientiousness.

Our intention is not to dismiss research to date in this field. Although we remain agnostic about whether IC is vitally important for AP (consistent with our studies), intuition suggests that it must play some role. However, in scientific

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[16] Moreover, when we used our estimate of $\rho = .20$ for the NFC–AP association in this model, these figures become 57% (g–AP), 35% (C–AP), and 7% (NFC–AP, $p = .12$).

research, we heed the general caution of Josh Billings: “Wisdum don’t konsist in knowing more that iz new, but in knowing less that iz false” (Billings, 1874, p. 430). We conclude that the definitive study showing the significance of IC for predicting academic outcomes is yet to be conducted.

9 CONCLUSIONS

9.1 Introduction

This chapter will discuss the overall significance of the studies within this thesis. First, it will re-state the *Findings* of each study briefly. Second, it will discuss the *Implications* of these findings in terms of investment traits, incremental validity, and investment theory. Third, it will provide *Future Directions* in four possible follow-up studies. Fourth, and finally, it will provide a *Concluding Statement*.

9.2 Findings

Here, the findings of the present series of studies will be summarised briefly. The first study assessed the number of factors to be found across items drawn from the TIE, NFC, and EC scales, and identified six: *Intellectual Avoidance*, *Deprivation*, *Problem Solving*, *Abstract Thinking*, *Reading*, and *Wide Interest*. It provided evidence for a higher-order factor that spanned these items and accounted for about 2/3 of the explained variance, while the first-order factors accounted for the remaining 1/3. It also included a Schmid-Leiman analysis indicating that items pertaining to the *Reading* factor loaded predominantly on their first-order factor, while the other factors loaded predominantly on the higher-order factor—indicating that reading habits (as measured by the TIE scale) may not fit within the IC domain. Moreover, a relative importance regression indicated that the three scales measured different profiles of factors; for instance, only the TIE scale measured *Reading*, and only the EC scale measured *Deprivation* (or D-type curiosity).

The second study aimed to replicate and extend the approach used in my honours study (Powell & Nettelbeck, 2014a) in order to assess the incremental validity of IC and confidence for predicting AP. Measures of Gf and Gc, FFM personality, two measures of IC (TIE and EC-D) and a measure of online confidence were used. No measure of IC possessed incremental validity for predicting AP above intelligence and FFM personality, and neither did confidence. Moreover, confidence appeared to possess a non-significant negative relationship with AP in this study. This unusual finding requires further research to substantiate. However, Conscientiousness remained a powerful predictor in each regression, and accounted for around 2/3 of explained variance. In conclusion, while this study did not provide support for the incremental validity of IC or confidence, it provided further support for the critical importance of Conscientiousness as an investment trait for academic outcomes.

The third study aimed to test investment theory in an adult population using university students, and whether reading habits could be incorporated within Mussel's Intellect domain. The investment theories of Cattell and Ackerman suggested that crystallised ability—the outcome of the investment of fluid ability—would become increasingly narrow once students left compulsory education, and therefore difficult to test in adults. Therefore, using psychology students, this study assessed whether the proposed investment traits of IC and confidence predicted incremental variance in domain-specific psychology knowledge above Gf, and whether these traits moderated this relationship. Here, confidence predicted variance in the outcome variable above Gf while IC did not, and neither showed any evidence of moderation. However, the measure of domain-specific psychology knowledge had poor reliability, which weakens the strength of this finding. Moreover, although the reading scale developed to complement the Intellect scale improved overall reliability, evidence from confirmatory factor analysis indicated that the Reading scale was likely to be redundant within this framework. In conclusion, this study suggested that confidence held more promise as an investment trait than did IC, and that there was no obvious benefit to incorporating reading habits within the Intellect scale.

Given the general lack of incremental validity obtained in Studies 2 and 3, Study 4 re-examined the argument of von Stumm, Hell, et al. (2011) that IC is the "third pillar" of academic performance alongside intelligence and conscientiousness. It was argued that the correlation between TIE and AP—on which their conclusion depended heavily—was miscalculated, and was based on three rather than four studies. This meant that the confidence intervals were wider than those reported, and called into question the accuracy of their obtained estimate. Moreover, although estimates for the TIE–AP correlation were around ρ = .3 (based on three correlations), TIE and NFC correlated very strongly, and estimates for the NFC–AP correlation (using 12 correlations) were closer to ρ = .2, suggesting that the best estimate for the TIE–AP correlation is probably nearer ρ = .2 than .3. When the NFC–AP correlation was substituted for the TIE–AP correlation, the path estimate for NFC–AP was reduced substantially. Given these issues, this study concluded that the true degree of incremental validity for IC was difficult to estimate at present, and that a definitive study on IC as a predictor of AP had not yet been published.

9.3 Implications

When these results are considered in the context of other research on these issues, several implications emerge. These include implications for investment traits, their incremental validity, and for investment theory itself.

Investment Traits

Although many variables might function as investment traits, two are considered that have been identified previously as potentially important in this connection: IC and confidence. This section will address theoretical issues relating to measuring these traits, while the next section will assess their practical relevance as incremental predictors of academic performance.

Intellectual curiosity. As has been stated several times already, there are several measures spread across diverse domains of research that measure IC. The present studies have provided further evidence on which to judge whether one (or more) of these scales is the most suitable to use in future research. To assess this question, we will consider six issues: (1) the existence of a higher-order IC factor, (2) I-type and D-type curiosity, (3) reading habits, (4) creativity, and (5) negatively-worded items, and (6) IC within the investment process.

Higher-order intellectual curiosity factor. Several lines of evidence from our studies indicate that a broad factor for IC overarches the content of these scales—as was suggested by Tanaka et al. (1988). Powell and Nettelbeck (2014a) reported that a single factor extracted from the scale totals of the TIE, NFC, EC, and IPIP–Intellect scales accounted for 72% of the explained variance across these scales. This result was consistent with the finding of Mussel (2010) who reported that a single factor extracted from the totals of six IC scales accounted for 67% of the explained variance. The findings of the Study 1 also provided support for the existence of a higher-order factor that spanned all the factors identified through exploratory factor analysis, except for *Reading*. This finding is consistent with the validation study of Mussel

(2013a), who found that several constructs (including TIE, NFC, and EC) could be well-integrated within the Intellect domain.

Further, Study 3 has a more minor bearing on this issue, suggesting that reading habits are more closely aligned with this broad construct than other studies have indicated—discussed further below. The existence of this broad factor does not diminish the importance of its sub-factors, but it does indicate that this domain possesses a hierarchical structure. The conclusion here is that the ideal measure of IC would possess a hierarchical structure: a broad factor that overarches several theoretically-distinct but related sub-domains.

I-type and D-type curiosity. The findings of the Study 1 also provided support for the distinctiveness of D-type curiosity within the IC domain. Of the IC scales assessed (TIE, NFC, and EC), only EC measured D-type curiosity. Because the motivation behind D-type curiosity is argued to come from discomfort arising from a perceived lack of knowledge (rather than I-type, argued to arise from the enjoyment of learning), this construct appears to be a theoretically distinct aspect of information-seeking behaviour. This position has been supported empirically by research on systems of the brain that are engaged for I-type and D-type curiosity (Litman, 2005), by evidence suggesting that I-type curiosity overlaps more with tolerance for ambiguity, whereas D-type curiosity overlaps more with need for closure (Litman, 2010); and by cross-cultural research showing differential relationships between these constructs and measures of self-regulation (Lauriola et al., 2015). Taken together, these results suggest that future research within the IC domain should use a comprehensive framework that assesses both I-type and D-type curiosity.

Reading habits. The findings of the Study 1 indicated that the reading habits measured with items from the TIE scale are distinct from a broad factor overarching items from TIE, NFC, and EC scales. This raised the possibility that reading habits did not fit within the IC domain. However, Study 3 tested this idea by administering a reading scale developed specifically to align within Mussel's Intellect framework. Results indicated that these items were essentially redundant within the model. This being so, there is no obvious benefit in adding them to the existing scale, because its reliability of .96 is already extremely high. Although reading habits are almost certainly a core activity of those who are high in IC, they do not appear to provide additional explanatory power, and the *Learn* operation within the Intellect scale probably includes variance explained by reading habits. Based on the present studies, therefore, it is concluded that although reading habits could be added to the Intellect domain, there would be little point in doing so.

Creativity. Creativity has been discussed as part of major theories of intelligence (e.g. Carroll, 1993; Sternberg, 1984), potentially making its contribution in the domain of curiosity important to measure. Within the Intellect framework, Mussel (2013a) defined the Create operation as the "personality component of contributing toward creative intellectual achievements", whereby those who possess higher levels are oriented toward "novel and unusual solutions" (Mussel, 2013a, p. 3).

Several studies have assessed the relationship of creativity with intelligence. Kim (2005) conducted a meta-analysis assessing the relationship between creativity and intelligence, and reported findings that did not support the "threshold" theory—i.e. that IQ and creativity would be related up to, but not beyond, a threshold of IQ (possibly around 120). Instead, Kim (2005) reported correlations between different ranges of IQ and creativity of around *r* = .2, which indicated that the two domains overlap only modestly. However, Silvia (2008) argued that this association may have been attenuated because it was assessed using observed rather than latent variables; his own study reported a more substantial regression coefficient of β = .43, indicating moderate overlap between creativity and IQ. Following this line of enquiry, Nusbaum and Silvia (2011) assessed this overlap in terms of executive function, and argued that so-called "divergent" and "convergent" thinking may be more similar than has often been assumed. Moreover, other studies have also assessed the association between personality variables and measures of creativity (Batey, Furnham, & Safiullina, 2010; Furnham & Bachtiar, 2008), and have reported substantial associations between some FFM variables (especially Extraversion) and creativity—although the overlap was stronger when creativity was assessed as a self-report rather than as an ability trait.

Although this survey is not exhaustive, the trend in this research relating creativity to intelligence and personality variables appears to be drawing these variables together into a closer theoretical account—a trend that is consistent with the approach that informs the Intellect framework. Indeed, Loewenstein (1994) noted concerning curiosity, cognitive ability, and creativity, "…it would be disturbing *not* to find a positive interrelationship among these three constructs" (p. 79). However, of the major measures of IC surveyed here, only the Intellect scale measures creativity. It is concluded here that the ideal scale measuring IC would include creativity as a component.

Negatively-worded items. A final consideration is the issue of whether the results of factor analyses of IC scales have been affected by the presence of negatively-worded items. Bors et al. (2006) assessed this issue for the NFC scale, and concluded that item polarity was responsible for producing trait-method factors. However, Furnham and Thorne (2013) factor-analysed a 34-item positively-worded NFC scale, and found evidence for three factors—indicating that the multiple factors identified previously for the 34-item NFC scale may not simply have been due to item-polarity. Given these issues, it remains possible that the factor labelled *Intellectual Avoidance* in Study 1 was a method factor caused by negatively-worded items. If so, a factor analysis of positively-worded equivalent items from across these scales may have yielded only five factors. Given this uncertainty, it is suggested that in future the ideal scale would have only positively-worded items, to avoid this potential confound.

Intellectual curiosity within the investment process. Although the results of the studies reported here, which have assessed the incremental validity of IC (and Confidence) for predicting AP, also inform this issue, we will discuss these matters in a separate section below. Study 3 assessed whether the investment process could be observed through the relationships between Gf, IC, and acquired domain-specific psychology knowledge in university students. Contrary to expectations, this was not demonstrated in this study—although the poor reliability of the measure of domain-specific psychology knowledge may have obscured these relationships. The finding (discussed below) that Confidence predicted variance beyond variance explained by Gf in domain-specific knowledge suggests that this variance was, at least in part, able to be predicted, despite the poor alpha. Moreover, outside the academic context, much of the evidence for IC as an investment trait relies on the work of Ackerman, whose studies have provided evidence that is consistent with the idea that personality variables relating to IC influence the degree to which adult knowledge is acquired. However, the present studies have found little evidence that IC is uniquely important in the investment process, Nonetheless, it is recognised that this suggestion must be tempered by other evidence suggesting that IC might be important to investment.

Confidence. In addition to the implications of these findings for IC, they also relate to interest in confidence as a variable that influences investment. Two issues are addressed here: (1) the overlap of confidence with personality variables, and (2) confidence within the investment process.

Overlap of confidence with personality variables. Burns et al. (2016) assessed confidence in both online and self-report forms, and concluded that self-reported confidence overlaps more substantially with FFM personality (especially Emotional Stability/Neuroticism), and that online confidence overlaps more substantially with abilities. However, an overlap between Openness to Experience and online confidence was also reported by Stankov and Lee (2008), who yoked confidence assessments to measures of verbal comprehension. In Study 2, confidence correlated negligibly and non-significantly with FFM variables, except for its moderate correlation with Openness to Experience ($r = .40$, $p < .01$). Moreover, confidence also overlapped substantially with measures of IC (TIE: $r = .42$; NFC: $r = .46$; EC: $r = .28$; all ps < .01), indicating that a significant overlap may exist between the IC domain and confidence. Nonetheless, although the FFM variables were not reported in the analyses, in Study 3 confidence did not correlate significantly with any FFM variable, nor with any measure of IC (Intellect, OE, and NFC). At this stage no firm conclusion can be drawn about a relationship between IC and confidence, and further research is required.

A possible explanation for this discrepancy concerns how confidence was measured: Study 2 attached confidence ratings to measures of intelligence, whereas

Study 3 attached them to the experimental measure of domain-specific psychology knowledge. Therefore, it was possible that in Study 2 the overlap between confidence and both Openness to Experience and IC variables was due to their shared variance with intelligence. However, this possibility was tested by calculating their partial correlation controlling for Gf and Gc, and all these correlations remained significant and substantial (OE: $r = .32$; TIE: $r = .29$; NFC: $r = .34$; EC $r = .23$; all ps $< .01$). This suggests that these associations are not due simply to the shared associations with intelligence.

To interpret this overlap, it is tempting to suggest that confidence and Openness to Experience correlate because they both are located within a broad domain that encompasses these (and possibly other) investment traits. Potentially, higher levels of confidence may predispose individuals to engage in new experiences and to entertain new ideas, fostering greater Openness to Experience and IC over time. However, this speculation is highly tentative, and requires substantially more research to evaluate it. In conclusion, research has yet to establish a clear pattern of association between online confidence and FFM variables—possibly except for Openness to Experience.

Confidence within the investment process. Study 3 found that the confidence ratings yoked to a measure of cognitive ability predicted substantial variance in domain-specific psychology knowledge. This finding is consistent with investment theory, and with Stankov's suggestion that confidence may be a uniquely important metacognitive trait that serves to assess a person's strengths and weakness, and indicates where best to apply his or her intellectual abilities (Stankov, 1999, 2013; Stankov & Lee, 2017). Moreover, it provides some evidence that the process of investment may be observable in adults if the outcome measures are constrained appropriately to relevant domain-specific knowledge—despite the strength of this evidence being weakened by the poor reliability of the outcome measure. This is also consistent with the study of Rolfhus and Ackerman (1999), who demonstrated that personality variables (TIE and Openness to Experience) and interest types predicted adult domain-specific knowledge in the a way consistent with PPIK theory. It is concluded that the studies reported here have provided qualified evidence for confidence as an investment trait.

Conclusion. When considered in the context of available research, the present studies support the use of the Intellect scale as a reliable and theoretically-informed measure of IC. This scale assesses IC as a hierarchical structure, measures both I-type and D-type curiosity (reconfigured as Seek and Conquer processes, respectively), excludes reading habits, assesses creativity and does not contain negatively-worded items. Moreover, it captures the essence of existing scales within this domain, and its high reliability has been demonstrated now in both German and Australian samples. It is concluded that Mussel's Intellect scale is the best current measure of the IC domain, and should be used in future research.

Furthermore, findings reported here suggest that the domains of IC and confidence may overlap substantially, and that future studies should attempt to assess their relationship more thoroughly. Moreover, this direct comparison of these investment traits suggests that confidence may be the more promising candidate—although previous research that emphasises IC in this regard should not be dismissed.

Incremental validity

From investment theory, it follows that investment traits should possess incremental validity above intelligence and FFM variables. Here, the contribution of the present studies to assessing the incremental validity of IC will be considered under two headings: (1) the extent of incremental validity for IC, and (2) the variability of IC–AP associations.

The extent of incremental validity for intellectual curiosity. Here, the studies assessing the incremental validity of IC measures for predicting AP will be divided into three categories: substantial incremental validity, modest incremental validity, and no incremental validity. Only a single study appears to have provided strong evidence of incremental validity, that of Chamorro-Premuzic et al. (2006), which demonstrated that TIE explained 3–9% more variance than did cognitive ability and FFM personality measures in a sample of university students. Although von Stumm, Hell, et al. (2011) might also be placed in this category, that study will be addressed below.

Several studies have indicated only modest incremental validity for measures of IC. Furnham et al. (2009) assessed the contribution of TIE in the context of measures of cognitive ability and FFM personality for British secondary students. In their regressions, TIE only added 2–3% incremental validity above demographic variables and cognitive ability—FFM variables were then added in the final step. Powell and Nettelbeck (2014a) assessed the incremental validity of several measures of IC for university entrance scores, and found that TIE predicted 1.8% incremental variance above cognitive ability and Conscientiousness, while NFC, EC, and IPIP-Intellect predicted no significant incremental variance. Consistent with this, in a large-scale study assessing German secondary students, Schroeders et al. (2015) reported incremental validity of 0.5–1.8% across several subjects for TIE after accounting for gender, migration background, SES variables, subject-specific interest, and fluid intelligence. Notably, this study did not assess FFM personality variables; it is possible that including these (especially Conscientiousness) may have eliminated entirely the reported incremental validity of TIE. Finally, the second study reported here found no incremental validity in AP for measures of IC above cognitive ability or FFM variables within a university population. Therefore, having added the present studies to the extant research, it is concluded that evidence for the incremental validity of IC remains mixed.

This state of affairs calls into question the meta-analysis of von Stumm, Hell, et al. (2011), and especially its conclusion that IC is the "third pillar" of academic performance, with a predictive power rivalling that of Conscientiousness. It also raises the question of how to explain this variability among different studies, a question that is now addressed.

The variability of IC–AP associations. It is suggested that the incremental validity of IC varies because the associations between different measures of IC and AP also vary substantially. Although only a few studies have assessed the question of incremental validity, far more have reported zero-order correlations between IC and AP. In this regard, Study 2 found zero-order correlations between AP and both TIE and NFC fell short of statistical significance (r = .16, p = .06), and, most importantly, they did not predict incremental variance above measures of intelligence and FFM personality variables. This study therefore indicated only a modest overlap between IC and AP.

The most relevant research with which to compare the results of Study 2 is that of Chamorro-Premuzic et al. (2006), which used a very similar approach and a similar sample. Interestingly, this study reported an uncommon pattern of relationships between TIE, Openness to Experience, and the four measures of AP. The correlation between TIE and Openness to Experience was unusually low ($r = .24$, $p < .05$)—especially considering theoretical debate concerning whether these are in fact the same construct (Ackerman & Goff, 1994; Rocklin, 1994). This low correlation may also have been responsible for the differential patterns of relationship between these variables and the four measures of AP, where TIE predicted substantial variance in each AP measure (ranging from $r = .28$ to .45, all $p < .01$), while Openness to Experience predicted no significant variance in any AP measure (ranging from $r = -.13$ to .11, all $p > .05$). The TIE appears to have been the standard scale (Goff & Ackerman, 1992), and the established measure of the NEO-FFI was used to measure FFM personality (Costa & McCrae, 1992b). Moreover, in the final regression model assessing the incremental validity of TIE, Conscientiousness was not a significant predictor of variance in AP—an uncommon finding.

It is plausible that these unusual relationships may reflect idiosyncrasies of the sample, and do not call into question the results themselves. A possible explanation for this discrepancy concerns the selection procedures for university courses, where differences between approaches in Britain and Australia may result in less restriction of range for academic ability in one of these groups. Overall, however, when the results of Chamorro-Premuzic et al. (2006) are considered alongside Study 2, they indicate that further research is required to understand the reasons for the substantial variability observed for associations between IC and AP.

The variability among correlations between IC and AP at the meta-analytic level is now considered further. As noted in Study 4, von Stumm and Ackerman (2013) compared the correlations between AP and both NFC and TIE, and reported correlations of $\rho = .22$ (AP–NFC; random effects model) and .29 (AP–TIE). Although this would appear to indicate that TIE predicts AP more substantially than does NFC, there are two *prima facie* reasons from the current studies that suggest doubt about this: (1) the manifest correlations between these variables in current studies have been very strong, being $r = .87$ and .81 (Powell & Nettelbeck, 2014a; Powell et al., 2017, respectively); and (2) the correlations between these variables and AP are nearly identical, being $r = .35$ and .33 for TIE and NFC respectively (Powell & Nettelbeck, 2014a), and $r = .16$ for both (Powell et al., 2017). Therefore, the reason for the substantial difference in meta-analytic coefficients must lie elsewhere.

A likely explanation for this difference concerns the cohorts in question: the 12 studies assessing the AP–NFC correlation all assessed university students, while two of the three studies assessing the AP–TIE relationship used secondary students. Given the considerations listed above, for this exercise it is assumed that their correlations with AP were interchangeable. The studies reported in von Stumm and Ackerman (2013) plus those from the present series of studies, Powell and Nettelbeck (2014a), and the study of Furnham et al. (2009), were grouped according to educational level. This resulted in four correlations between TIE/NFC and AP for secondary students with a median correlation of $r = .33$, and 15 correlations between TIE/NFC and AP for tertiary students with a median value of $r = .20$. Therefore, based on this limited evidence, the association between IC and AP appears to be stronger in secondary students than in tertiary students. This point is highly significant, and has strong implications for the approach of von Stumm, Hell, et al. (2011) who treated secondary and tertiary cohorts interchangeably; whereas the evidence available suggests that they are not. Moreover, results from Study 4 have indicated that what might appear to be a trivial difference between correlations of ρ = .3 and .2 for the IC–AP relationship results in a non-trivial difference for the final model.

Conclusion. Therefore, it can be concluded that the evidence available for the incremental validity of IC provides mixed support, which moderates the sweeping conclusion of von Stumm, Hell, et al. (2011). Moreover, there is sufficient variability in the underlying associations between IC and AP to warrant further investigation for why this might be so.

Investment Theory

Assimilation or accommodation? As Chapter 1 made clear, investment theory has received mixed support from studies that have assessed it. This should not be surprising because a theory first proposed some 70 years ago has had ample time for its predictions to be assessed and challenged. To help assess the status of investment theory, a key part of Piaget's theory of cognitive development (Piaget, 1964) will be invoked. Although Piaget formulated this theory to account for childhood cognitive development, it also captures the process by which theories mature.

Piaget argued that the development of knowledge structures in children involves three related processes: assimilation, accommodation, and equilibration. Defined briefly, assimilation means fitting new knowledge within existing knowledge structures, accommodation means modifying knowledge structures to fit new knowledge, and equilibration is the process that regulates assimilation and accommodation. When the knowledge structures are in equilibrium—that is, when knowledge structures are sufficient to make sense of new information—assimilation is preferred, but when they are in disequilibrium, accommodation takes place to return the system to equilibrium (Piaget, 1964).

If investment theory is assessed in Piagetian terms, the weight of evidence contradicting some of its basic assumptions indicates that assimilation is no longer an option. In this regard, the judgment of Schweizer and Koch (2002) seems appropriate: "The failure to confirm a basic assumption of a theory leaves two alternatives: rejection or revision. The high intuitive appeal of Investment Theory suggests that revision should be preferred over rejection" (p. 59). Therefore, to survive, investment theory must be developed to accommodate the evidence that has accumulated since Cattell proposed it.

Increased complexity. The kind of changes that investment theory must undergo will very likely make it more complex, because this appears to have been the case for each suggested revision since its proposal. Three issues in particular suggest the need for a more complex investment theory: state and trait curiosity, genotypic-environmental covariance, and the Dickens and Flynn model of the development of intelligence. These will be surveyed in turn.

State and trait curiosity. As noted in Chapter 2, a longstanding issue is the relationship between state and trait measures of curiosity. The example of Epistemic Curiosity illustrates this: its early history under Berlyne involved the state approach, whereas its latter history under Litman, Mussel, and others has involved the trait approach, as have approaches to most other recent measures of IC. This shift in approach may have been driven by convenience, because self-report personality questionnaires are easier to administer than experimentally manipulating curiosity itself in a laboratory setting. However, this time-saving probably has come at the cost of further explanatory power that could be provided by a more complex model.

In this regard, the model of Litman, Hutchins, et al. (2005) maintains the state-trait distinction. It suggests that a chain reaction takes place between components of curiosity: trait curiosity exerts an influence on state curiosity, which then influences exploratory behaviour. According to this model, someone who possesses strong trait curiosity is differentially more likely to experience strong state curiosity than someone with less trait curiosity. Although situational factors should also be expected to influence state curiosity, ultimately it is state curiosity that is proposed to be the proximal cause of exploratory behaviour—a view affirmed by Loewenstein (1994), who argued that state curiosity held “greater promise” than trait curiosity for predicting behaviour (p. 79). If this model is correct—or is at least a closer approximation of the real-world relationship between these variables—then approaches that assesses only trait measures of curiosity are missing critical information. Including all relevant variables would have the potential to provide a more powerful account of the variables that are the consequence of exploratory behaviour—including academic achievement, knowledge, or other forms of Gc. Therefore, although state and trait approaches to curiosity probably measure constructs that overlap substantially, these are not identical, and a more complex revision of investment theory might seek to integrate both aspects of curiosity.

Genotypic-environmental covariance. Another issue that demonstrates clearly the need for a more complex formulation of investment theory is the mounting evidence for the significance of genotypic-environmental covariance. Cattell’s view on the relative heritability of Gf and Gc made much intuitive sense: Gf should have relatively stronger heritability because it derives from innate, biological capacities, while Gc should have relatively weaker heritability because it is determined largely from cultural preferences. However, recent evidence indicates that this is not the case (Kan et al., 2013), leading to discussions around the important contribution of genotypic-environmental covariance.

This issue will be returned to shortly, but it should be noted that both Cattell and Ackerman remarked that the investment process would probably be more complex than either of their theories indicated. This applies both to the issue of the relationship between Gf and Gc, and to the relationship between interests and abilities. Explaining his rationale for preferring the labels Gf and Gc over "process" and "product" respectively, Cattell (1963) suggested that:

> ...the capacity to learn is not only a function of the process (fluid ability) but often of the product, as well as of personality and motivation. Particularly when aids have been acquired, the rate of learning is a function not only of fluid ability but of the crystallized products of former application of process. (1963, p. 2, footnote 2)

Moreover, Ackerman (1996) made a similar suggestion concerning the relationship between interests and abilities, suggesting that they might develop "along mutually causal lines":

> That is, abilities and interests develop in tandem, such that ability level determines the probability of success in a particular task domain, and personality/interests determine the motivation for attempting the task. Thus, subsequent to *successful* attempts at task performance, interest in the task

> domain may increase, along with the knowledge level for that task. Conversely, *unsuccessful* attempts at task performance may result in a decrement in interest for that domain… (1996, pp. 244-5, italics in original)

Therefore, although a superficial reading of their theories may suggest simple, directional relationships between the components of intellectual investment, both authors clearly recognised that real-world investment would contain a level of complexity that exceeded their theoretical specifications.

Returning to the issue of Cattell's heritability estimates, probably the most powerful challenge to this aspect of investment theory has been the landmark study of Kan et al. (2013), who concluded that the most heritable abilities are also the most culture-dependent, and that a test's loading on a factor for general intelligence is a function of its cultural load. Moreover, it has also become clear that heritability estimates of general intelligence gradually increase with age, rising from about 20% in infancy to around 80% in adulthood (Plomin & Deary, 2015). These findings obviously contradict Cattell's intuition about the relative heritabilities of Gf and Gc, and highlight the need for a more elaborate account of the relationship between these variables.

To explain these relationships, the contribution of genotypic-environmental covariance has been proposed. Briley and Tucker-Drob (2013) have suggested that genotypic-environmental covariance comes in two forms, labelled *innovation* and *amplification*. In the early developmental period (up to around 8 years) they found evidence for genetic innovation, where genes that were previously inactive are "switched on" because of environmental effects. However, in the latter developmental period (after about 8 years) they reported that genetic amplification took over, where propensities conferred by genes are amplified subsequently by environmental factors. Thus, in contrast to a simplistic, directional view where nature is static and nurture is dynamic, this viewpoint suggests that both are dynamic and interact in complex ways.

Dickens and Flynn model of intelligence. In this regard, Dickens and Flynn (2001) have provided a detailed account of how nature and nurture might interplay in the development of intelligence. Flynn (1984, 1987) drew attention to the very substantial increase of scores on intelligence tests across the twentieth century of on average approximately 3 IQ points every 10 years—the so-called Flynn Effect. He has argued extensively that this rise cannot be due solely to genetic factors, and must therefore be caused by changes in the environment. However, because heritability estimates indicate that intelligence is highly heritable—possibly being around .75 (Neisser et al., 1996)—this results in the so-called IQ paradox expressed in the question: How can IQ be strongly heritable and yet be strongly influenced by the environment?

Dickens and Flynn (2001) developed their model of intelligence to resolve this paradox. This demonstrates how interaction between genetic and environmental factors might account for the observed rise in intelligence test scores. In brief, the model specifies that small initial differences in cognitive ability conferred by genes are then amplified by the environment—the “amplification” noted by Briley and Tucker-Drob (2013). This amplification is proposed to take place through the influence of *individual multipliers* and *social multipliers*. On the one hand, individual multipliers are environmental factors that operate on an individual level. For instance, a student who has inherited slightly greater cognitive potential than another student might be placed in a class for gifted students, which increases this initial difference and allows this student to excel academically, gain entry to university, and increase this difference further. Over the course of many years, this small initial advantage becomes large, partly through individual multipliers. On the other hand, social multipliers operate on society broadly, and increase a population's ability at a task. Universal education could function as a social multiplier, where education is provided to an entire population, thereby increasing the knowledge base of everyone within that population. Overall, this approach suggests that including the influence of both individual and social multipliers can account for the observed, dramatic rise of IQ scores across the twentieth century—by modelling explicitly the kind of complex interactions that take place in the real world.

Connecting these last two issues, it is likely that investment theory needs to become sufficiently complex to deal with the issue of genotypic-environmental covariance, and that the Dickens and Flynn model of intelligence may highlight how this can be done. It has become clear that the relationship between Gf and Gc cannot be expressed merely by pointing a causal arrow from the former to the latter; the arrow very likely points in both directions. Moreover, it is possible that investment theory has received mixed support because the reciprocal relationship between Gf and Gc, and probably between these and proposed investment traits, has not been modelled adequately. Cattell recognised the need for this complexity, and Ackerman expressed it more fully in PPIK. However, when considering the complexity of genotypic-environmental covariance, future researchers may need to make investment theory more complex still, possibly by incorporating interaction and/or multiplier effects explicitly within their models.

Conclusion

In conclusion, multiple lines of evidence surveyed in this section indicate that the investment process is complex—probably much more complex than current investment theories have indicated. Given the state-trait distinction, the issue of genotypic-environmental covariance, and the instructive parallel of the Dickens and Flynn model of intelligence, investment theory will likely need to become more complex to model effectively the investment process in the real world, and therefore to remain relevant.

9.4 Future Directions

These considerations point to several potential follow-up studies, and four are suggested here: (1) a meta-analysis of NFC and AP, (2) a replication of Study 3, (3) the development of an objective measure of curiosity, and (4) a revision of investment theory. These are now considered in turn, ordered from least to most difficult.

Meta-analysis of Need for Cognition and Academic Performance

An obvious future direction would be to repeat the approach of von Stumm, Hell, et al. (2011) using NFC instead of TIE. Although von Stumm, Hell, et al. (2011) stated that they chose TIE over other IC measures because it had attracted the most research attention, this claim is clearly questionable; the subsequent meta-analysis of von Stumm and Ackerman (2013) revealed that NFC possesses a research base about four times larger. Obviously, this makes it a more suitable candidate for meta-analysis, where the strength of the conclusions is largely a function of the number of studies available to analyse. Moreover, it would be far better to assess secondary or tertiary populations independently. The IC–AP association differs according to educational level, which is also the case for cognitive ability and Conscientiousness (Poropat, 2009), and so modelling these within a particular level of education would produce more accurate outcomes. For NFC, such analysis would need to be undertaken using tertiary students because nearly all the research on its relationship with academic performance relates to this group.

A Replication of Study 3

Although it is argued here that Study 3 was well-conceived, its major shortcoming was the poor reliability of the measure of domain-specific psychology knowledge. To produce a reliable measure that assessed more adequately psychology knowledge as a single dimension, a multi-stage process of item administration and selection would need to be undertaken first to develop the scale. Moreover, Rolfhus and Ackerman (1999) provided evidence that TIE relates more strongly to humanities-type subjects than with mathematics and science subjects. Therefore, although Schroeders et al. (2015) found limited evidence for the incremental validity of TIE, this was for math and science subjects in secondary students and may not be generalisable to other subject domains. Repeating the approach of the Study 3, but using students in other disciplines (e.g. medicine or engineering), could provide further evidence of the investment process in adults, and whether this takes place differently within distinct disciplines. It would also provide another opportunity to compare the relative efficacy of IC and confidence as investment traits.

The Development of an Objective Measure of Intellectual Curiosity

Chapter 2 concluded that a significant shift had taken place from measuring curiosity as a state to measuring it as a trait. Although necessary and helpful, this shift has possibly led to a general neglect of the importance of measuring curiosity as a state. The potential value of developing an objective measure of IC is suggested by two observations. First, preference for novelty is an objective measure that appears to parallel IC in adults, and is a major predictor of later life outcomes. And second, recent evidence suggests that the more objective measures of personality (i.e. other-rated assessments) can predict substantially more variance in AP than can more subjective measures. Other-reported personality assessments may be particularly valuable for Conscientiousness, because this trait has a strong behavioural component (Pytlik Zillig, Hemenover, & Dienstbier, 2002), and it has been found to predict a substantially larger proportion of variance in AP when assessed by other-report (ρ = .38) than by self-report (ρ = .22) measures (Poropat, 2014).

Finally, recent research has attempted to assess IC in accordance with the dual-process model of self-concept (see the overview by Smith & DeCoster, 2000), by validating versions of the Implicit Association Test (IAT; Greenwald, McGhee, & Schwartz, 1998) designed to measure NFC. Fleischhauer et al. (2013) and Fleischhauer et al. (2015) have compared explicit NFC (measured by self-report) with implicit NFC (measured using IAT), and reported that these constructs related differentially to reflective and spontaneous behaviour. Although these studies have not yet established clearly whether these measures assess the same underlying construct, potentially they represent a move toward assessing personality constructs in ways that are potentially less susceptible to the limitations of self-report.

A Revision of Investment Theory

The last proposed follow-up study, and almost certainly the most difficult, would be to revise investment theory itself. As argued earlier, a substantial body of evidence has accrued since Cattell first proposed investment theory, which has called into question his major premise that Gf is static and relatively independent of cultural influence, while Gc is dynamic and strongly influenced by culture. Instead, developmental perspectives have shifted to viewing both as taking part in a complex and dynamic interplay. Ackerman's PPIK theory goes further than Cattell's original statement in modelling this complexity, but arguably still is not sufficiently complex to capture the real-world process—which means that investment theory must now accommodate these perspectives that challenge some of its major predictions. This accommodation might involve incorporating both state and trait measures of curiosity, and modelling genotypic-environmental covariance as the Dickens and Flynn model of intelligence does.

Lastly, it is likely that some investment traits might only serve investment in some situations. For example, Conscientiousness appears to be an important investment trait in the context of AP, but does not appear to have a strong relationship with the development of general knowledge in adults. As noted earlier Cattell's insight was that there might be as many forms of Gc as there are occupations, and this point stands. But to extend—and exaggerate—this point, it might be said that that there are as many investment theories as there are investment domains. Future research on IC, confidence, and Conscientiousness could clarify this possibility.

9.5 Concluding Statement

The present series of studies aimed to assess investment traits intellectual curiosity and confidence as predictors of academic performance. In this regard, it is concluded that (1) the incremental validity of IC for predicting AP needs to be re-evaluated because of limitations in, and substantial variations between, the major studies that have reported this. Moreover, when considering the influence of investment traits more generally, it is concluded that (2) the contribution of IC toward investment outcomes may have been overstated, but the contribution of confidence may have been underappreciated. Finally, when these findings are considered in the context of research addressing investment theory since its proposal, it is concluded that (3) investment theory remains viable, but needs to be revised substantially to accommodate several findings that have contradicted specific predictions that follow from it.

This thesis will conclude by drawing attention to an observation made in Chapter 2 regarding the history of curiosity research. The single best measure of intelligence in infancy—the only measure that predicts substantial variance in adult intelligence and AP—is preference for novelty. This construct looks remarkably like measures of curiosity that have been developed for adults, which is not surprising since they have common ancestry in Berlyne's accounts of curiosity. What is surprising, however, is that this basic measure that overlaps with both curiosity and intelligence for infants becomes associated predominantly with personality traits in adulthood—traits that conventionally have been defined as *independent* of intelligence. Given that this construct has been used to demonstrate a strong continuity for intelligence across the lifespan, demarcating clearly between intelligence and all personality variables in adulthood has the potential to provide a misleading perspective on their relationship. They are probably not as distinct as they have been expected to be.

Since Cattell first proposed investment theory, evidence has been mounting that the investment process is complex for both children and adults. And the more investment theory takes its cues from the close interplay between curiosity and intelligence during infancy, the better it will capture this process during adulthood.

Indeed, this may be why the incremental validity of IC as an “investment trait” has been difficult to demonstrate: for adults as well as for infants, it seems that intelligence and curiosity are not identical, just inseparable.

References

Ackerman, P. L. (1988). Determinants of individual differences during skill acquisition: Cognitive abilities and information processing. *Journal of Experimental Psychology: General, 117*(3), 288-318. doi:10.1037/0096-3445.117.3.288

Ackerman, P. L. (1996). A theory of adult intellectual development: Process, personality, interests, and knowledge. *Intelligence, 22*(2), 227-257. doi:10.1016/S0160-2896(96)90016-1

Ackerman, P. L. (2000). Domain-specific knowledge as the "dark matter" of adult intelligence Gf/Gc: Personality and interest correlates. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 55*(2), 69-84. doi:10.1093/geronb/55.2.P69

Ackerman, P. L., & Goff, M. (1994). Typical intellectual engagement and personality: Reply to Rocklin (1994). *Journal of Educational Psychology, 86*(1), 150-153. doi:10.1037/0022-0663.86.1.150

Ackerman, P. L., & Heggestad, E. D. (1997). Intelligence, personality, and interests: Evidence for overlapping traits. *Psychological Bulletin, 121*(2), 219-245. doi:10.1037//0033-2909.121.2.219

Ackerman, P. L., Kanfer, R., & Goff, M. (1995). Cognitive and noncognitive determinants and consequences of complex skill acquisition. *Journal of Experimental Psychology: Applied, 1*(4), 270-304. doi:10.1037/1076-898X.1.4.270

Ackerman, P. L., & Rolfhus, E. L. (1999). The locus of adult intelligence: Knowledge, abilities, and nonability traits. *Psychology and Aging, 14*(2), 314-330. doi:10.1037/0882-7974.14.2.314

Allport, G., & Odbert, H. (1936). Trait-names: A psycho-lexical study. *Psychological Monographs, 47*(1), 1-171. doi:10.1037/h0093360

Arteche, A., Chamorro-Premuzic, T., Ackerman, P. L., & Furnham, A. (2009). Typical intellectual engagement as a byproduct of openness, learning approaches, and self-assessed intelligence. *Educational Psychology, 29*(3), 357-367. doi:10.1080/01443410902927833

Ashton, M. C., Lee, K., & Son, C. (2000). Honesty as the sixth factor of personality: Correlations with Machiavellianism, primary psychopathy, and social adroitness. *European Journal of Personality, 14*(4), 359-368. doi:10.1002/1099-0984(200007/08)14:4<359::AID-PER382>3.0.CO;2-Y

Ashton, M. C., Lee, K., Vernon, P. A., & Jang, K. L. (2000). Fluid intelligence, crystallized intelligence, and the Openness/Intellect factor. *Journal of Research in Personality, 34*(2), 198-207. doi:10.1006/jrpe.1999.2276

Baddeley, A., Emslie, H., & Nimmo-Smith, I. (1993). The Spot-the-Word test: A robust estimate of verbal intelligence based on lexical decision. *British Journal of Clinical Psychology, 32*(1), 55-65. doi:10.1111/j.2044-8260.1993.tb01027.x

Batey, M., Furnham, A., & Safiullina, X. (2010). Intelligence, general knowledge and personality as predictors of creativity. *Learning and Individual Differences, 20*(5), 532-535. doi:10.1016/j.lindif.2010.04.008

Bayley, N. (1955). On the growth of intelligence. *American Psychologist, 10*(12), 805-818. doi:10.1037/h0043803

Berlyne, D. E. (1949). 'Interest' as a psychological concept. *British Journal of Psychology. General Section, 39*(4), 184-195. doi:10.1111/j.2044-8295.1949.tb00219.x

Berlyne, D. E. (1950). Novelty and curiosity as determinants of exploratory behaviour. *British Journal of Psychology. General Section, 41*(1-2), 68-80. doi:10.1111/j.2044-8295.1950.tb00262.x

Berlyne, D. E. (1954). A theory of human curiosity. *British Journal of Psychology. General Section, 45*(3), 180-191. doi:10.1111/j.2044-8295.1954.tb01243.x

Berlyne, D. E. (1957). Conflict and information—theory variables as determinants of human perceptual curiosity. *Journal of Experimental Psychology, 53*(6), 399-404. doi:10.1037/h0049194

Berlyne, D. E. (1958). The influence of complexity and novelty in visual figures on orienting responses. *Journal of Experimental Psychology, 55*(3), 289-296. doi:10.1037/h0043555

Berlyne, D. E. (1960). *Conflict, arousal, and curiosity*. New York: McGraw-Hill.

Berlyne, D. E. (1966). Curiosity and exploration. *Science, 153*(3731), 25-33. doi:10.1126/science.153.3731.25

Billings, J. (1874). *Everybody's friend, or Josh Billing's encyclopedia and proverbial philosophy of wit and humor*. Hartford, CN: American Publishing Company.

Binet, A., & Simon, T. (1905). New methods for the diagnosis of the intellectual level of subnormals. *L'annee Psychologique, 12*, 191-244.

Block, J. (1995). A contrarian view of the five-factor approach to personality description. *Psychological Bulletin, 117*(2), 187-215. doi:10.1037/0033-2909.117.2.187

Bors, D. A., & Stokes, T. L. (1998). Raven's Advanced Progressive Matrices: Norms for first-year university students and the development of a short form. *Educational* *and Psychological Measurement, 58*(3), 382-398. doi:10.1177/0013164498058003002

Bors, D. A., Vigneau, F., & Lalande, F. (2006). Measuring the need for cognition: Item polarity, dimensionality, and the relation with ability. *Personality and Individual Differences, 40*(4), 819-828. doi:10.1016/j.paid.2005.09.007

Brebner, J. (2003). *The quick scales-R*. Adelaide, Australia.: School of Psychology, University of Adelaide.

Briley, D. A., Domiteaux, M., & Tucker-Drob, E. M. (2014). Achievement-relevant personality: Relations with the Big Five and validation of an efficient instrument. *Learning and Individual Differences, 32*, 26-39. doi:10.1016/j.lindif.2014.03.010

Briley, D. A., & Tucker-Drob, E. M. (2013). Explaining the increasing heritability of cognitive ability across development: A meta-analysis of longitudinal twin and adoption studies. *Psychological Science, 24*(9), 1704-1713. doi:10.1177/0956797613478618

Burns, K. M., Burns, N. R., & Ward, L. (2016). Confidence—more a personality or ability trait? It depends on how it is measured: A comparison of young and older adults. *Frontiers in Psychology, 7*, 1-14. doi:doi.org/10.3389/fpsyg.2016.00518

Cacioppo, J. T., & Petty, R. E. (1982). The need for cognition. *Journal of Personality and Social Psychology, 42*(1), 116-131. doi:10.1037/0022-3514.42.1.116

Cacioppo, J. T., Petty, R. E., Feinstein, J. A., & Jarvis, W. B. G. (1996). Dispositional differences in cognitive motivation: The life and times of individuals varying in need for cognition. *Psychological Bulletin, 119*(2), 197-253. doi:10.1037/0033-2909.119.2.197

Cacioppo, J. T., Petty, R. E., & Kao, C. F. (1984). The efficient assessment of need for cognition. *Journal of Personality Assessment, 48*(3), 306-307. doi:10.1207/s15327752jpa4803_13

Cacioppo, J. T., Petty, R. E., & Morris, K. J. (1983). Effects of need for cognition on message evaluation, recall, and persuasion. *Journal of Personality and Social Psychology, 45*(4), 805-818. doi:10.1037/0022-3514.45.4.805

Carroll, J. B. (1993). *Human cognitive abilities: A survey of factor-analytic studies*. Cabmridge, UK: Cambridge University Press.

Cattell, R. B. (1943). The measurement of adult intelligence. *Psychological Bulletin, 40*(3), 153-193. doi:10.1037/h0059973

Cattell, R. B. (1963). Theory of fluid and crystallized intelligence: A critical experiment. *Journal of Educational Psychology, 54*(1), 1-22. doi:10.1037/h0046743

Cattell, R. B. (1966). The scree test for the number of factors. *Multivariate Behavioral Research, 1*(2), 245-276. doi:10.1207/s15327906mbr0102_10

Cattell, R. B. (1971). *Abilities: their structure, growth, and action*. Boston, MA: Houghton Mifflin.

Cattell, R. B. (1987). *Intelligence: Its structure, growth and action*. Amsterdam: North-Holland.

Cattell, R. B., Eber, H. W., & Tatsuoka, M. (1970). Handbook for the 16 personality factor questionnaire. *Champaign, IL: Institute for Personality and Ability Testing*.

Chamorro-Premuzic, T., & Furnham, A. (2003). Personality traits and academic examination performance. *European Journal of Personality, 17*(3), 237-250. doi:10.1002/per.473

Chamorro-Premuzic, T., & Furnham, A. (2005). *Personality and Intellectual Competence*. New York: Taylor & Francis Group.

Chamorro-Premuzic, T., & Furnham, A. (2008). Personality, intelligence and approaches to learning as predictors of academic performance. *Personality and Individual Differences, 44*(7), 1596-1603. doi:10.1016/j.paid.2008.01.003

Chamorro-Premuzic, T., Furnham, A., & Ackerman, P. L. (2006). Incremental validity of the typical intellectual engagement scale as predictor of different academic performance measures. *Journal of Personality Assessment, 87*(3), 261-268. doi:10.1207/s15327752jpa8703_07

Christensen, H., Batterham, P. J., & Mackinnon, A. J. (2013). The getting of wisdom: Fluid intelligence does not drive knowledge acquisition. *Journal of Cognition and Development, 14*(2), 321-331. doi:10.1080/15248372.2012.664590

Cohen, A. R., Stotland, E., & Wolfe, D. M. (1955). An experimental investigation of need for cognition. *The Journal of Abnormal and Social Psychology, 51*(2), 291-294. doi:10.1037/h0042761

Collins, R. P., Litman, J. A., & Spielberger, C. D. (2004). The measurement of perceptual curiosity. *Personality and Individual Differences, 36*(5), 1127-1141. doi:10.1016/S0191-8869(03)00205-8

Costa, P. T., & McCrae, R. R. (1992a). Four ways five factors are basic. *Personality and Individual Differences, 13*(6), 653-665. doi:10.1016/0191-8869(92)90236-I

Costa, P. T., & McCrae, R. R. (1992b). *Revised NEO personality inventory (NEO PI-R) and NEO five-factor inventory (NEO FFI): Professional manual*. Odessa, FL: Psychological Assessment Resources.

Davis, T. L., Severy, L. J., Kraus, S. J., & Whitaker, J. M. (1993). Predictors of sentencing decisions: The beliefs, personality variables, and demographic factors of juvenile justice. *Journal of Applied Social Psychology, 23*(6), 451-477. doi:10.1111/j.1559-1816.1993.tb01098.x

Deary, I. J., Strand, S., Smith, P., & Fernandes, C. (2007). Intelligence and educational achievement. *Intelligence, 35*(1), 13-21. doi:10.1016/j.intell.2006.02.001

Dellenbach, M., & Zimprich, D. (2008). Typical intellectual engagement and cognition in old age. *Aging, Neuropsychology, and Cognition: A Journal on Normal and Dysfunctional Development, 15*(2), 208-231. doi:10.1080/13825580701338094

DeYoung, C. G., Hirsh, J. B., Shane, M. S., Papademetris, X., Rajeevan, N., & Gray, J. R. (2010). Testing predictions from personality neuroscience brain structure and the big five. *Psychological Science, 21*(6), 820-828. doi:10.1177/0956797610370159

DeYoung, C. G., Quilty, L. C., & Peterson, J. B. (2007). Between facets and domains: 10 aspects of the Big Five. *Journal of Personality and Social Psychology, 93*(5), 880-896. doi:10.1037/0022-3514.93.5.880

DeYoung, C. G., Shamosh, N. A., Green, A. E., Braver, T. S., & Gray, J. R. (2009). Intellect as distinct from Openness: differences revealed by fMRI of working memory. *Journal of Personality and Social Psychology, 97*(5), 883-892. doi:10.1037/a0016615

Dickens, W. T., & Flynn, J. R. (2001). Heritability estimates versus large environmental effects: The IQ paradox resolved. *Psychological Review, 108*(2), 346-369. doi:10.1037/0033-295X.108.2.346

Digman, J. M. (1997). Higher-order factors of the Big Five. *Journal of Personality and Social Psychology, 73*(6), 1246-1256. doi:10.1111/j.2044-8295.2010.02006.x

Eysenck, H. J. (1978). Superfactors P, E and N in a comprehensive factor space. *Multivariate Behavioral Research, 13*(4), 475-481. doi:10.1207/s15327906mbr1304_7

Fabrigar, L. R., Wegener, D. T., MacCallum, R. C., & Strahan, E. J. (1999). Evaluating the use of exploratory factor analysis in psychological research. *Psychological Methods, 4*(3), 272-299. doi:10.1037/1082-989X.4.3.272

Fagan, J. F. (1966). Short-term retention in normal and retarded children. *Psychonomic Science, 6*(6), 303-304. doi:10.3758/BF03328078

Fagan, J. F. (1970). Memory in the infant. *Journal of Experimental Child Psychology, 9*(2), 217-226. doi:10.1016/0022-0965(70)90087-1

Fagan, J. F. (1974). Infant color perception. *Science, 183*(4128), 973-975. doi:10.1126/science.183.4128.973

Fagan, J. F. (1976). Infants' recognition of invariant features of faces. *Child Development, 47*, 627-638. doi:10.1111/j.1467-8624.1976.tb02226.x

Fagan, J. F. (1977a). An attention model of infant recognition. *Child Development, 48*, 345-359. doi:10.1111/j.1467-8624.1977.tb01171.x

Fagan, J. F. (1977b). Infant recognition memory: Studies in forgetting. *Child Development, 48*, 68-78. doi:10.1111/j.1467-8624.1977.tb04244.x

Fagan, J. F. (1981). Infant intelligence. *Intelligence, 5*(3), 239-243. doi:10.1016/S0160-2896(81)80011-6

Fagan, J. F. (1984). The intelligent infant: Theoretical implications. *Intelligence, 8*(1), 1-9. doi:10.1016/0160-2896(84)90002-3

Fagan, J. F. (2000). A theory of intelligence as processing: Implications for society. *Psychology, Public Policy, and Law, 6*(1), 168-179. doi:10.1037/1076-8971.6.1.168

Fagan, J. F. (2011). Intelligence in infancy. In R. Sternberg & S. Kaufman (Eds.), *The Cambridge handbook of intelligence* (pp. 130-142). Cambridge, UK: Cambridge University Press.

Fagan, J. F., Holland, C. R., & Wheeler, K. (2007). The prediction, from infancy, of adult IQ and achievement. *Intelligence, 35*(3), 225-231. doi:10.1016/j.intell.2006.07.007

Fagan, J. F., & McGrath, S. K. (1981). Infant recognition memory and later intelligence. *Intelligence, 5*(2), 121-130. doi:10.1016/0160-2896(81)90002-7

Fantz, R. L. (1956). A method for studying early visual development. *Perceptual and Motor Skills, 6,* 13-15. doi:10.2466/PMS.6..13-15

Fantz, R. L. (1964). Visual experience in infants: Decreased attention to familiar patterns relative to novel ones. *Science, 146*(3644), 668-670. doi:10.1126/science.146.3644.668

Ferguson, E. (1999). A facet and factor analysis of typical intellectual engagement (TIE): Associations with locus of control and the five factor model of personality. *Social Behavior and Personality, 27*(6), 545-561. doi:10.2224/sbp.1999.27.6.545

Ferrer, E., & McArdle, J. J. (2004). An experimental analysis of dynamic hypotheses about cognitive abilities and achievement from childhood to early adulthood. *Developmental Psychology, 40*(6), 935-952. doi:10.1037/0012-1649.40.6.935

Fleischhauer, M., Enge, S., Brocke, B., Ullrich, J., Strobel, A., & Strobel, A. (2010). Same or different? Clarifying the relationship of need for cognition to personality and intelligence. *Personality and Social Psychology Bulletin, 36*(1), 82-96. doi:10.1177/0146167209351886

Fleischhauer, M., Strobel, A., Enge, S., & Strobel, A. (2013). Assessing implicit cognitive motivation: developing and testing an implicit association test to measure need for cognition. *European Journal of Personality, 27*(1), 15-29. doi:10.1002/per.1841

Fleischhauer, M., Strobel, A., & Strobel, A. (2015). Directly and indirectly assessed need for cognition differentially predict spontaneous and reflective information processing behavior. *Journal of Individual Differences, 36*(2), 101-109. doi:10.1027/1614-0001/a000161

Flynn, J. R. (1984). The mean IQ of Americans: Massive gains 1932 to 1978. *Psychological Bulletin, 95*(1), 29-51. doi:10.1037/0033-2909.95.1.29

Flynn, J. R. (1987). Massive IQ gains in 14 nations: What IQ tests really measure. *Psychological Bulletin, 101*(2), 171-191. doi:10.1037/0033-2909.101.2.171

Furnham, A., & Bachtiar, V. (2008). Personality and intelligence as predictors of creativity. *Personality and Individual Differences, 45*(7), 613-617. doi:10.1016/j.paid.2008.06.023

Furnham, A., Chamorro-Premuzic, T., & McDougall, F. (2003). Personality, cognitive ability, and beliefs about intelligence as predictors of academic performance. *Learning and Individual Differences, 14*(1), 47-64. doi:10.1016/j.lindif.2003.08.002

Furnham, A., Monsen, J., & Ahmetoglu, G. (2009). Typical intellectual engagement, Big Five personality traits, approaches to learning and cognitive ability predictors of academic performance. *British Journal of Educational Psychology, 79*(4), 769-782. doi:10.1348/978185409X412147

Furnham, A., & Thorne, J. D. (2013). Need for Cognition. *Journal of Individual Differences, 34*(4), 230-240. doi:10.1027/1614-0001/a000119

Galton, F. (1855). *The art of travel, or, Shifts and contrivances available in wild countries*. London, UK: John Murray.

Galton, F. (1869). *Hereditary genius: An inquiry into its laws and consequences*. London, UK: Macmillan.

Galton, F. (1907). Cutting a round cake on scientific principles. *Nature, 75*(1938), 173. doi:10.1038/075173c0

Goff, M., & Ackerman, P. L. (1992). Personality-intelligence relations: Assessment of typical intellectual engagement. *Journal of Educational Psychology, 84*(4), 537-552. doi:10.1037/0022-0663.84.4.537

Goldberg, L. R. (1992). The development of markers for the Big-Five factor structure. *Psychological Assessment, 4*(1), 26-42. doi:10.1037/1040-3590.4.1.26

Goldberg, L. R. (1999). A broad-bandwidth, public domain, personality inventory measuring the lower-level facets of several five-factor models. In I. Mervielde, I. Deary, P. De Fruyt, & F. Ostendorf (Eds.), *Personality Psychology in Europe* (Vol. 7, pp. 7-28). Tilburg, The Netherlands: Tilburg University Press.

Greenwald, A. G., McGhee, D. E., & Schwartz, J. L. (1998). Measuring individual differences in implicit cognition: The implicit association test. *Journal of*

Personality and Social Psychology, 74(6), 1464-1480. doi:10.1037/0022-3514.74.6.1464

Grömping, U. (2006). Relative importance for linear regression in R: The package relaimpo. *Journal of Statistical Software, 17*(1), 1-27. doi:10.18637/jss.v017.i01

Gurven, M., von Rueden, C., Massenkoff, M., Kaplan, H., & Lero Vie, M. (2013). How universal is the Big Five? Testing the five-factor model of personality variation among forager–farmers in the Bolivian Amazon. *Journal of Personality and Social Psychology, 104*(2), 354-370. doi:10.1037/a0030841

Gustafsson, J.-E., & Undheim, J. O. (1992). Stability and change in broad and narrow factors of intelligence from ages 12 to 15 years. *Journal of Educational Psychology, 84*(2), 141-149. doi:10.1037/0022-0663.84.2.141

Hakstian, A. R., & Cattell, R. B. (1978). Higher-stratum ability structures on a basis of twenty primary abilities. *Journal of Educational Psychology, 70*(5), 657-669. doi:10.1037/0022-0663.70.5.657

Hakstian, A. R., & Woolsey, L. K. (1985). Validity studies using the Comprehensive Ability Battery (CAB): IV. Predicting achievement at the university level. *Educational and Psychological Measurement, 45*(2), 329-341. doi:10.1177/001316448504500218

Hebb, D. O. (1942). The effect of early and late brain injury upon test scores, and the nature of normal adult intelligence. *Proceedings of the American Philosophical Society, 85*(3), 275-292. doi:jstor.org/stable/985007

Hill, B. D., Foster, J. D., Elliott, E. M., Shelton, J. T., McCain, J., & Gouvier, W. D. (2013). Need for cognition is related to higher general intelligence, fluid intelligence, and crystallized intelligence, but not working memory. *Journal of Research in Personality, 47*(1), 22-25. doi:10.1016/j.jrp.2012.11.001

Holland, J. L. (1959). A theory of vocational choice. *Journal of Counseling Psychology, 6*(1), 35-45. doi:10.1037/h0040767

Holland, J. L. (1973). *Making vocational choices: A theory of careers*. Englewood Cliffs, NJ: Prentice Hall.

Holland, J. L. (1996). Exploring careers with a typology: What we have learned and some new directions. *American Psychologist, 51*(4), 397-406. doi:10.1037/0003-066X.51.4.397

Horn, J. L. (1965). A rationale and test for the number of factors in factor analysis. *Psychometrika, 30*(2), 179-185. doi:10.1007/BF02289447

Hu, L. t., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal, 6*(1), 1-55. doi:10.1080/10705519909540118

Jensen, A. R. (1998). *The g factor: The science of mental ability*. Westport, CT: Praeger

Jensen, A. R. (2002). Galton's legacy to research on intelligence. *Journal of Biosocial Science, 34*(02), 145-172. doi:10.1017/S0021932002001451

John, O. P., Naumann, L. P., & Soto, C. J. (2008). Paradigm shift to the integrative big five trait taxonomy. In O. P. John, R. W. Robins, & L. A. Pervin (Eds.), *Handbook of personality: Theory and research* (3rd ed., pp. 114-158). New York: The Guilford Press.

Johnson, W., & Bouchard, T. J. (2005). The structure of human intelligence: It is verbal, perceptual, and image rotation (VPR), not fluid and crystallized. *Intelligence, 33*(4), 393-416. doi:10.1016/j.intell.2004.12.002

Judge, T. A., Jackson, C. L., Shaw, J. C., Scott, B. A., & Rich, B. L. (2007). Self-efficacy and work-related performance: the integral role of individual differences. *Journal of Applied Psychology, 92*(1), 107-127. doi:10.1037/0021-9010.92.1.107

Kan, K.-J., Kievit, R. A., Dolan, C., & van der Maas, H. (2011). On the interpretation of the CHC factor Gc. *Intelligence, 39*(5), 292-302. doi:10.1016/j.intell.2011.05.003

Kan, K.-J., Wicherts, J. M., Dolan, C. V., & van der Maas, H. L. (2013). On the nature and nurture of intelligence and specific cognitive abilities: The more heritable, the more culture dependent. *Psychological Science, 24*(12), 1-9. doi:10.1177/0956797613493292

Keith, T. Z., & Reynolds, M. R. (2010). Cattell–Horn–Carroll abilities and cognitive tests: What we've learned from 20 years of research. *Psychology in the Schools, 47*(7), 635-650. doi:10.1002/pits.20496

Kim, K. H. (2005). Can only intelligent people be creative? A meta-analysis. *Journal of Secondary Gifted Education, 16*(2-3), 57-66. doi:10.4219/jsge-2005-473

Kleitman, S., & Stankov, L. (2007). Self-confidence and metacognitive processes. *Learning and Individual Differences, 17*(2), 161-173. doi:10.1016/j.lindif.2007.03.004

Konečni, V. J. (1978). Daniel E. Berlyne: 1924-1976. *The American Journal of Psychology*, 133-137. doi:jstor.org/stable/1421829

Konečni, V. J. (1996). Daniel E. Berlyne (1924–1976): two decades later. *Empirical Studies of the Arts, 14*(2), 129-142.

Ku, K. Y., & Ho, I. T. (2010). Dispositional factors predicting Chinese students' critical thinking performance. *Personality and Individual Differences, 48*(1), 54-58. doi:10.1016/j.paid.2009.08.015

Kuncel, N. R., Hezlett, S. A., & Ones, D. S. (2004). Academic performance, career potential, creativity, and job performance: Can one construct predict them all? *Journal of Personality and Social Psychology, 86*(1), 148-161. doi:10.1037/0022-3514.86.1.148

Laidra, K., Pullmann, H., & Allik, J. (2007). Personality and intelligence as predictors of academic achievement: A cross-sectional study from elementary to secondary school. *Personality and Individual Differences, 42*(3), 441-451. doi:10.1016/j.paid.2006.08.001

Langevin, R. (1971). Is curiosity a unitary construct? *Canadian Journal of Psychology/Revue canadienne de psychologie, 25*(4), 360-374. doi:10.1037/h0082397

Langevin, R. (1976). Construct validity of sensation seeking and curiosity measures of normal and psychotic subjects. *Canadian Journal of Behavioural Science/Revue canadienne des sciences du comportement, 8*(3), 251-262. doi:10.1037/h0081953

Lauriola, M., Litman, J. A., Mussel, P., De Santis, R., Crowson, H. M., & Hoffman, R. R. (2015). Epistemic curiosity and self-regulation. *Personality and Individual Differences, 83*, 202-207. doi:10.1016/j.paid.2015.04.017

Lee, J. (2009). Universals and specifics of math self-concept, math self-efficacy, and math anxiety across 41 PISA 2003 participating countries. *Learning and Individual Differences, 19*(3), 355-365. doi:10.1016/j.lindif.2008.10.009

Lichtenstein, S., & Fischhoff, B. (1977). Do those who know more also know more about how much they know? *Organizational Behavior and Human Performance, 20*(2), 159-183. doi:10.1016/0030-5073(77)90001-0

Lievens, F., Ones, D. S., & Dilchert, S. (2009). Personality scale validities increase throughout medical school. *Journal of Applied Psychology, 94*(6), 1514-1535. doi:10.1037/a0016137

Lindeman, R. H., Merenda, P. F., & Gold, R. Z. (1980). *Introduction to bivariate and multivariate analysis*. Harlow, UK: Longman Higher Education.

Litman, J. A. (2005). Curiosity and the pleasures of learning: Wanting and liking new information. *Cognition and Emotion, 19*(6), 793-814. doi:10.1080/02699930541000101

Litman, J. A. (2008). Interest and deprivation factors of epistemic curiosity. *Personality and Individual Differences, 44*(7), 1585-1595. doi:10.1016/j.paid.2008.01.014

Litman, J. A. (2009). Curiosity and metacognition. In C. B. Larson (Ed.), *Metacognition: New research developments* (pp. 105-116). Pauppauge, NY: Nova Science Publishers.

Litman, J. A. (2010). Relationships between measures of I- and D-type curiosity, ambiguity tolerance, and need for closure: An initial test of the wanting-liking model of information-seeking. *Personality and Individual Differences, 48*(4), 397-402. doi:10.1016/j.paid.2009.11.005

Litman, J. A., Collins, R. P., & Spielberger, C. D. (2005). The nature and measurement of sensory curiosity. *Personality and Individual Differences, 39*(6), 1123-1133. doi:10.1016/j.paid.2005.05.001

Litman, J. A., Crowson, H. M., & Kolinski, K. (2010). Validity of the Interest- and Deprivation-type epistemic curiosity distinction in non-students. *Personality and Individual Differences, 49*(5), 531-536. doi:10.1016/j.paid.2010.05.021

Litman, J. A., Hutchins, T. L., & Russon, R. K. (2005). Epistemic curiosity, feeling-of-knowing, and exploratory behaviour. *Cognition and Emotion, 19*(4), 559-582. doi:10.1080/02699930441000427

Litman, J. A., & Jimerson, T. L. (2004). The measurement of curiosity as a feeling of deprivation. *Journal of Personality Assessment, 82*(2), 147-157. doi:10.1207/s15327752jpa8202_3

Litman, J. A., & Mussel, P. (2013). Validity of the interest-and deprivation-type epistemic curiosity model in Germany. *Journal of Individual Differences, 34*(2), 59-68. doi:10.1027/1614-0001/a000100

Litman, J. A., & Spielberger, C. D. (2003). Measuring epistemic curiosity and its diversive and specific components. *Journal of Personality Assessment, 80*(1), 75-86. doi:10.1207/S15327752JPA8001_16

Loewenstein, G. (1994). The psychology of curiosity: A review and reinterpretation. *Psychological Bulletin, 116*(1), 75-98. doi:10.1037/0033-2909.116.1.75

Luong, C., Strobel, A., Wollschläger, R., Greiff, S., Vainikainen, M.-P., & Preckel, F. (2017). Need for cognition in children and adolescents: Behavioral correlates and relations to academic achievement and potential. *Learning and Individual Differences, 53*, 103-113. doi:10.1016/j.lindif.2016.10.019

MacDonald, A. P. (1970). Revised scale for ambiguity tolerance: Reliability and validity. *Psychological Reports, 26*(3), 791-798. doi:10.2466/pr0.1970.26.3.791

Major, J. T., Johnson, W., & Deary, I. J. (2012). Comparing models of intelligence in Project TALENT: The VPR model fits better than the CHC and extended Gf–Gc models. *Intelligence, 40*(6), 543-559. doi:10.1016/j.intell.2012.07.006

McArdle, J. J., Hamagami, F., Meredith, W., & Bradway, K. P. (2000). Modeling the dynamic hypotheses of Gf–Gc theory using longitudinal life-span data. *Learning and Individual Differences, 12*(1), 53-79. doi:10.1016/S1041-6080(00)00036-4

Morony, S., Kleitman, S., Lee, Y. P., & Stankov, L. (2013). Predicting achievement: Confidence vs self-efficacy, anxiety, and self-concept in Confucian and European countries. *International Journal of Educational Research, 58*, 79-96. doi:10.1016/j.ijer.2012.11.002

Moutafi, J., Furnham, A., & Crump, J. (2006). What facets of Openness and Conscientiousness predict fluid intelligence score? *Learning and Individual Differences, 16*(1), 31-42. doi:10.1016/j.lindif.2005.06.003

Moutafi, J., Furnham, A., & Paltiel, L. (2004). Why is Conscientiousness negatively correlated with intelligence? *Personality and Individual Differences, 37*(5), 1013-1022. doi:10.1016/j.paid.2003.11.010

Murray, A. L., Johnson, W., McGue, M., & Iacono, W. G. (2014). How are conscientiousness and cognitive ability related to one another? A re-examination of the intelligence compensation hypothesis. *Personality and Individual Differences, 70*, 17-22. doi:10.1016/j.paid.2014.06.014

Mussel, P. (2010). Epistemic curiosity and related constructs: Lacking evidence of discriminant validity. *Personality and Individual Differences, 49*(5), 506-510. doi:10.1016/j.paid.2010.05.014

Mussel, P. (2013a). Intellect: a theoretical framework for personality traits related to intellectual achievements. *Journal of Personality and Social Psychology, 104*(5), 885-906. doi:10.1037/a0031918

Mussel, P. (2013b). Introducing the construct curiosity for predicting job performance. *Journal of Organizational Behavior, 34*(4), 453-472. doi:10.1002/job.1809

Neisser, U., Boodoo, G., Bouchard Jr, T. J., Boykin, A. W., Brody, N., Ceci, S. J., . . . Sternberg, R. J. (1996). Intelligence: Knowns and unknowns. *American Psychologist, 51*(2), 77-101. doi:10.1037/0003-066X.51.2.77

Newland, T. (1962). *The assessment of exceptional children*. New York: Prentice-Hall.

Nicolas, S., Andrieu, B., Croizet, J.-C., Sanitioso, R. B., & Burman, J. T. (2013). Sick? Or slow? On the origins of intelligence as a psychological object. *Intelligence, 41*(5), 699-711. doi:10.1016/j.intell.2013.08.006

Nusbaum, E. C., & Silvia, P. J. (2011). Are intelligence and creativity really so different?: Fluid intelligence, executive processes, and strategy use in divergent thinking. *Intelligence, 39*(1), 36-45. doi:10.1016/j.intell.2010.11.002

O'Connor, M. C., & Paunonen, S. V. (2007). Big Five personality predictors of post-secondary academic performance. *Personality and Individual Differences, 43*(5), 971-990. doi:10.1016/j.paid.2007.03.017

Olson, K., & Camp, C. (1984). Factor analysis of curiosity measures in adults. *Psychological Reports, 54*(2), 491-497. doi:10.2466/pr0.1984.54.2.491

Olson, K., Camp, C., & Fuller, D. (1984). Curiosity and need for cognition. *Psychological Reports, 54*(1), 71-74. doi:10.2466/pr0.1984.54.1.71

Pallier, G., Wilkinson, R., Danthiir, V., Kleitman, S., Knezevic, G., Stankov, L., & Roberts, R. D. (2002). The role of individual differences in the accuracy of confidence judgments. *The Journal of General Psychology, 129*(3), 257-299. doi:10.1080/00221300209602099

Paunonen, S. V., & Ashton, M. C. (2001). Big Five predictors of academic achievement. *Journal of Research in Personality, 35*(1), 78-90. doi:10.1006/jrpe.2000.2309

Paunonen, S. V., & Jackson, D. N. (2000). What is beyond the big five? Plenty! *Journal of Personality, 68*(5), 821-835. doi:10.1111/1467-6494.00117

Pavlov, I. P. (1927). *Conditioned reflexes. An Investigation of the physiological activity of the cerebral cortex* (G. Anrep, Trans.). Toronto, CA: Oxford University Press.

Piaget, J. (1952). *The origins of intelligence in children* (M. Cook, Trans. Vol. 8). New York: International Universities Press.

Piaget, J. (1964). Part I: Cognitive development in children: Piaget. Development and learning. *Journal of Research in Science Teaching, 2*(3), 176-186. doi:10.1002/tea.3660020306

Piotrowski, J. T., Litman, J. A., & Valkenburg, P. (2014). Measuring epistemic curiosity in young children. *Infant and Child Development, 23*(5), 542-553. doi:10.1002/icd.1847

Plomin, R., & Deary, I. J. (2015). Genetics and intelligence differences: five special findings. *Molecular Psychiatry, 20*(1), 98-108. doi:10.1038/mp.2014.105

Poropat, A. E. (2009). A meta-analysis of the five-factor model of personality and academic performance. *Psychological Bulletin, 135*(2), 322-338. doi:10.1037/a0014996

Poropat, A. E. (2014). Other-rated personality and academic performance: evidence and implications. *Learning and Individual Differences, 34*, 24-32. doi:10.1016/j.lindif.2014.05.013

Powell, C., & Nettelbeck, T. (2014a). Intellectual curiosity may not incrementally predict academic success. *Personality and Individual Differences, 64*, 7-11. doi:10.1016/j.paid.2014.01.045

Powell, C., & Nettelbeck, T. (2014b). May intellectual curiosity prevail. *Personality and Individual Differences, 70*, 254-256. doi:10.1016/j.paid.2014.06.017

Powell, C., Nettelbeck, T., & Burns, N. R. (2016). Deconstructing intellectual curiosity. *Personality and Individual Differences, 95*, 147-151. doi:10.1016/j.paid.2016.02.037

Powell, C., Nettelbeck, T., & Burns, N. R. (2017). The incremental validity of curiosity and confidence for predicting academic performance in advanced tertiary students. *Personality and Individual Differences, 116*, 51-56. doi:10.1016/j.paid.2017.04.011

Preckel, F. (2014). Assessing need for cognition in early adolescence: Validation of a German adaption of the Cacioppo/Petty Scale. *European Journal of Psychological Assessment, 30*(1), 65-72. doi:10.1027/1015-5759/a000170

Pytlik Zillig, L. M. P., Hemenover, S. H., & Dienstbier, R. A. (2002). What do we assess when we assess a Big 5 trait? A content analysis of the affective, behavioral, and cognitive processes represented in Big 5 personality inventories. *Personality and Social Psychology Bulletin, 28*(6), 847-858. doi:10.1177/0146167202289013

R Development Core Team. (2014). R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing.

Raven, J. C., Raven, J. E., & Court, J. H. (1998). *Manual for Raven's Progressive Matrices and Vocabulary Scales: The Mill Hill Vocabulary Scale*. Oxford: Oxford Psychologists Press.

Richards, J. B., Litman, J., & Roberts, D. H. (2013). Performance characteristics of measurement instruments of epistemic curiosity in third-year medical students. *Medical Science Educator, 23*(3), 355-363. doi:10.1007/BF03341647

Richardson, M., Abraham, C., & Bond, R. (2012). Psychological correlates of university students' academic performance: A systematic review and meta-analysis. *Psychological Bulletin, 138*(2), 353-387. doi:10.1037/0022-0663.90.2.224

Rindermann, H., Flores-Mendoza, C., & Mansur-Alves, M. (2010). Reciprocal effects between fluid and crystallized intelligence and their dependence on parents' socioeconomic status and education. *Learning and Individual Differences, 20*(5), 544-548. doi:10.1016/j.lindif.2010.07.002

Rocklin, T. (1994). Relation between typical intellectual engagement and openness: Comment on Goff and Ackerman (1992). *Journal of Educational Psychology, 86*(1), 145-149. doi:10.1037/0022-0663.86.1.145

Rolfhus, E. L., & Ackerman, P. L. (1996). Self-report knowledge: At the crossroads of ability, interest, and personality. *Journal of Educational Psychology, 88*(1), 174-188. doi:10.1037/0022-0663.88.1.174

Rolfhus, E. L., & Ackerman, P. L. (1999). Assessing individual differences in knowledge: Knowledge, intelligence, and related traits. *Journal of Educational Psychology, 91*(3), 511-526. doi:10.1037//0022-0663.91.3.511

Rose, S. A., Feldman, J. F., & Jankowski, J. J. (2012). Implications of infant cognition for executive functions at age 11. *Psychological Science, 23*(11), 1345-1355. doi:10.1177/0956797612444902

Roth, B., Becker, N., Romeyke, S., Schäfer, S., Domnick, F., & Spinath, F. M. (2015). Intelligence and school grades: A meta-analysis. *Intelligence, 53*, 118-137. doi:10.1016/j.intell.2015.09.002

Sadowski, C. J. (1993). An examination of the short need for cognition scale. *The Journal of Psychology, 127*(4), 451-454. doi:10.1080/00223980.1993.9915581

Schaie, K. W., & Strother, C. R. (1968). A cross-sequential study of age changes in cognitive behavior. *Psychological Bulletin, 70*(6), 671-680. doi:10.1037/h0026811

Schipolowski, S., Wilhelm, O., & Schroeders, U. (2014). On the nature of crystallized intelligence: The relationship between verbal ability and factual knowledge. *Intelligence, 46*, 156-168. doi:10.1016/j.intell.2014.05.014

Schmid, J., & Leiman, J. M. (1957). The development of hierarchical factor solutions. *Psychometrika, 22*(1), 53-61. doi:10.1007/BF02289209

Schmidt, F. L., & Crano, W. D. (1974). A test of the theory of fluid and crystallized intelligence in middle-and low-socioeconomic-status children: A cross-lagged panel analysis. *Journal of Educational Psychology, 66*(2), 255-261. doi:10.1037/h0036093

Schroeders, U., Schipolowski, S., & Böhme, K. (2015). Typical intellectual engagement and achievement in math and the sciences in secondary education. *Learning and Individual Differences, 43*, 31-38. doi:10.1016/j.lindif.2015.08.030

Schuler, H., Hirn, J.-O. W., Hell, B., & Trapmann, S. (2007). Meta-analysis of the relationship between the big five and academic success at university. *Zeitschrift für Psychologie / Journal of Psychology, 215*(2), 132-151. doi:10.1027/0044-3409.215.2.132

Schulze, R., & Roberts, R. D. (2006). Assessing the Big Five. *Zeitschrift für Psychologie / Journal of Psychology, 214*(3), 133-149. doi:10.1026/0044-3409.214.3.133

Schweizer, K., & Koch, W. (2002). A revision of Cattell's investment theory: Cognitive properties influencing learning. *Learning and Individual Differences, 13*(1), 57-82. doi:10.1016/S1041-6080(02)00062-6

Siegler, R. S. (1992). The other Alfred Binet. *Developmental Psychology, 28*(2), 179-190. doi:10.1037/0012-1649.28.2.179

Silvia, P. J. (2008). Another look at creativity and intelligence: Exploring higher-order models and probable confounds. *Personality and Individual Differences, 44*(4), 1012-1021. doi:10.1016/j.paid.2007.10.027

Smith, E. R., & DeCoster, J. (2000). Dual-process models in social and cognitive psychology: Conceptual integration and links to underlying memory systems. *Personality and Social Psychology Review, 4*(2), 108-131. doi:10.1207/S15327957PSPR0402_01

Soares, D. L., Lemos, G. C., Primi, R., & Almeida, L. S. (2015). The relationship between intelligence and academic achievement throughout middle school: The role of students' prior academic performance. *Learning and Individual Differences, 41*, 73-78. doi:10.1016/j.lindif.2015.02.005

Sokolov, E. N. (1963). Higher nervous functions: The orienting reflex. *Annual Review of Physiology, 25*(1), 545-580. doi:10.1146/annurev.ph.25.030163.002553

Sokolov, E. N. (2001). Orienting Response. In P. B. Baltes (Ed.), *International Encyclopedia of the Social & Behavioral Sciences* (pp. 10978-10981). Oxford: Pergamon.

Spearman, C. (1904a). "General intelligence," objectively determined and measured. *The American Journal of Psychology, 15*(2), 201-292. doi:jstor.org/stable/1412107

Spearman, C. (1904b). The proof and measurement of association between two things. *The American Journal of Psychology, 15*(1), 72-101. doi:jstor.org/stable/1412159

Spearman, C. (1928). *The abilities of man: Their nature and measurement*. London: Macmillan.

Spielberger, C. D., Peters, R. A., & Frain, F. (1976). *The State-Trait Curiosity Inventory*. University of South Florida, Tampa.

Spinks, J. A., Näätänen, R., & Lyytinen, H. (2008). In memoriam: Evgeny Nikolaevich Sokolov (1920-2008). *Psychophysiology, 45*(6), 883-885. doi:10.1111/j.1469-8986.2008.00747.x

Stankov, L. (1999). Mining on the "no man's land" between intelligence and personality. In P. L. Ackerman, P. C. Kyllonen, & R. D. Roberts (Eds.), *Learning and individual differences: Process, trait, and content determinants* (pp. 315-337). Washington, DC: American Psychological Association.

Stankov, L. (2000). Complexity, metacognition, and fluid intelligence. *Intelligence, 28*(2), 121-143. doi:10.1016/S0160-2896(99)00033-1

Stankov, L. (2013). Noncognitive predictors of intelligence and academic achievement: An important role of confidence. *Personality and Individual Differences, 55*(7), 727-732. doi:10.1016/j.paid.2013.07.006

Stankov, L., & Crawford, J. D. (1996). Confidence judgments in studies of individual differences. *Personality and Individual Differences, 21*(6), 971-986. doi:10.1016/S0191-8869(96)00130-4

Stankov, L., & Crawford, J. D. (1997). Self-confidence and performance on tests of cognitive abilities. *Intelligence, 25*(2), 93-109. doi:10.1016/S0160-2896(97)90047-7

Stankov, L., Kleitman, S., & Jackson, S. A. (2015). Measures of the Trait of Confidence. In G. Boyle, D. Saklofske, & G. Matthews (Eds.), *Measures of Personality and Social Psychological Constructs* (pp. 158-189). London: Academic Press.

Stankov, L., & Lee, J. (2008). Confidence and cognitive test performance. *Journal of Educational Psychology, 100*(4), 961-976. doi:10.1037/a0012546

Stankov, L., & Lee, J. (2014). Overconfidence across world regions. *Journal of Cross-Cultural Psychology, 45*(5), 821-837. doi:10.1177/0022022114527345

Stankov, L., & Lee, J. (2017). Self-beliefs: Strong correlates of mathematics achievement and intelligence. *Intelligence, 61*, 11-16. doi:10.1016/j.intell.2016.12.001

Stankov, L., Lee, J., Luo, W., & Hogan, D. J. (2012). Confidence: A better predictor of academic achievement than self-efficacy, self-concept and anxiety? *Learning and Individual Differences, 22*(6), 747-758. doi:10.1016/j.lindif.2012.05.013

Stankov, L., Morony, S., & Lee, Y. P. (2014). Confidence: the best non-cognitive predictor of academic achievement? *Educational Psychology, 34*(1), 9-28. doi:10.1080/01443410.2013.814194

Steiger, J. H. (1990). Structural model evaluation and modification: An interval estimation approach. *Multivariate Behavioral Research, 25*(2), 173-180. doi:10.1207/s15327906mbr2502_4

Sternberg, R. J. (1984). Toward a triarchic theory of human intelligence. *Behavioral and Brain Sciences, 7*(2), 269-287. doi:10.1017/S0140525X00044629

Tanaka, J., Panter, A., & Winborne, W. C. (1988). Dimensions of the need for cognition: Subscales and gender differences. *Multivariate Behavioral Research, 23*(1), 35-50. doi:10.1207/s15327906mbr2301_2

Taube, K. T. (1997). Critical thinking ability and disposition as factors of performance on a written critical thinking test. *The Journal of General Education, 46*(2), 129-164. doi:jstor.org/stable/27797335

Thorsen, C., Gustafsson, J. E., & Cliffordson, C. (2014). The influence of fluid and crystallized intelligence on the development of knowledge and skills. *British Journal of Educational Psychology, 84*(4), 556-570. doi:10.1111/bjep.12041

Thurstone, L. L. (1938). *Primary Mental Abilities*. Chicago, IL: University of Chicago Press.

Tidwell, P. S., Sadowski, C. J., & Pate, L. M. (2000). Relationships between need for cognition, knowledge, and verbal ability. *The Journal of Psychology, 134*(6), 634-644. doi:10.1080/00223980009598242

Undheim, J. O., & Gustafsson, J.-E. (1987). The hierarchical organization of cognitive abilities: Restoring general intelligence through the use of linear structural relations (LISREL). *Multivariate Behavioral Research, 22*(2), 149-171. doi:10.1207/s15327906mbr2202_2

Valentin Kvist, A., & Gustafsson, J.-E. (2008). The relation between fluid intelligence and the general factor as a function of cultural background: A test of Cattell's investment theory. *Intelligence, 36*(5), 422-436. doi:10.1016/j.intell.2007.08.004

van der Linden, D., te Nijenhuis, J., & Bakker, A. B. (2010). The general factor of personality: A meta-analysis of Big Five intercorrelations and a criterion-related validity study. *Journal of Research in Personality, 44*(3), 315-327. doi:10.1016/j.jrp.2010.03.003

Vedel, A. (2014). The Big Five and tertiary academic performance: A systematic review and meta-analysis. *Personality and Individual Differences, 71*, 66-76. doi:10.1016/j.paid.2014.07.011

von Stumm, S., & Ackerman, P. L. (2013). Investment and intellect: A review and meta-analysis. *Psychological Bulletin, 139*(4), 841-869. doi:10.1037/a0030746

von Stumm, S., Chamorro-Premuzic, T., & Ackerman, P. L. (2011). Re-Visiting Intelligence–Personality Associations *The Wiley-Blackwell handbook of individual differences* (pp. 217-241). Oxford, UK: John Wiley & Sons Ltd.

von Stumm, S., & Furnham, A. (2012). Learning approaches: Associations with Typical Intellectual Engagement, intelligence and the Big Five. *Personality and Individual Differences, 53*(5), 720-723. doi:10.1016/j.paid.2012.05.014

von Stumm, S., Hell, B., & Chamorro-Premuzic, T. (2011). The hungry mind: Intellectual curiosity is the third pillar of academic performance. *Perspectives on Psychological Science, 6*(6), 574-588. doi:10.1177/1745691611421204

von Stumm, S., Hell, B., & Chamorro-Premuzic, T. (2014). Facts and findings: A reply to Powell and Nettelbeck (2014). *Personality and Individual Differences, 70*, 252-253. doi:10.1016/j.paid.2014.06.015

Webb, E. (1915). *Character and intelligence: An attempt at an exact study of character*. Cambridge, UK: Cambridge University Press.

Webster, D. M., & Kruglanski, A. W. (1994). Individual differences in need for cognitive closure. *Journal of Personality and Social Psychology, 67*(6), 1049-1062. doi:10.1037/0022-3514.67.6.1049

Wilhelm, O., Schulze, R., Schmiedek, F., & Süß, H.-M. (2003). Interindividuelle Unterschiede im typischen intellektuellen Engagement. *Diagnostica, 49*(2), 49-60. doi:10.1026//0012-1924.49.2.49

Woo, S. E., Harms, P. D., & Kuncel, N. R. (2007). Integrating personality and intelligence: Typical intellectual engagement and need for cognition. *Personality and Individual Differences, 43*(6), 1635-1639. doi:10.1016/j.paid.2007.04.022

Ziegler, M., Cengia, A., Mussel, P., & Gerstorf, D. (2015). Openness as a buffer against cognitive decline: The Openness-Fluid-Crystallized-Intelligence (OFCI) model applied to late adulthood. *Psychology and Aging, 30*(3), 573-588. doi:10.1037/a0039493

Ziegler, M., Danay, E., Heene, M., Asendorpf, J., & Bühner, M. (2012). Openness, fluid intelligence, and crystallized intelligence: Toward an integrative model. *Journal of Research in Personality, 46*(2), 173-183. doi:10.1016/j.jrp.2012.01.002

Appendix 1

Study 1: Pattern matrix of factor loadings for exploratory factor analysis with promax rotation for intellectual curiosity items

Scale and item number	Item*	*IA*	*D*	*PS*	*AT*	*R*	*WI*
NFC(17)	It's enough for me that something gets the job done; I don't care how or why it works.	**.78**	.02	-.06	.06	.00	-.07
TIE(7)		**.76**	.01	-.05	.00	-.02	-.17
TIE(6)		**.70**	.05	-.05	.03	-.02	-.18
TIE(42)		**.69**	.13	**-.21**	.09	-.05	.07
TIE(9)		**.66**	**.21**	-.12	-.19	-.01	-.05
NFC(4)	I would rather do something that requires little thought than something that is sure to challenge my thinking abilities.	**.66**	-.04	**.26**	-.04	.05	-.02
TIE(13)		**.62**	-.07	.09	.05	.07	-.08
TIE(49)		**.62**	-.04	-.04	-.07	-.13	.04
NFC(5)	I try to anticipate and avoid situations where there is a likely chance I will have to think in depth about something.	**.61**	-.13	.20	.06	.04	.03
NFC(3)	Thinking is not my idea of fun.	**.54**	-.03	.02	.09	.02	.19
TIE(12)		**.54**	.06	-.12	.07	-.01	**.29**
NFC(12)	Learning new ways to think doesn't excite me very much.	**.52**	.04	.02	.17	-.01	.16
TIE(48)		**.51**	.02	.02	**-.22**	.06	.14
NFC(7)	I only think as hard as I have to.	**.49**	-.13	**.25**	.07	.03	.01
NFC(9)	I like tasks that require little thought once I've learned them.	**.49**	-.12	**.36**	**-.24**	-.03	.13
TIE(52)		**.46**	-.04	**.35**	-.09	-.15	.03
TIE(36)		**.46**	.18	.06	-.01	-.01	**-.29**

NFC (8)	I prefer to think about small daily projects to long term ones.	**.44**	.00	-.01	.00	.03	.04
TIE(47)		**.38**	.09	.00	-.05	.02	-.03
TIE(57)		**.37**	.03	-.13	.12	**.26**	-.10
TIE(45)		**.36**	.04	.06	**.35**	-.06	-.14
TIE(54)		**.35**	-.09	.05	-.03	-.09	**.27**
TIE(51)		**.34**	-.17	**.22**	.01	-.10	.11
EC(5)	I find it fascinating to learn new information.	**.30**	**.29**	-.05	.12	.10	.13
TIE(31)		**.28**	-.01	-.13	.01	.09	-.05
TIE(4)		**.25**	.07	-.16	.03	.12	.19
TIE(20)		**.22**	-.13	.00	.12	.01	-.01
EC(6)	I feel frustrated if I can't figure out the solution to a problem, so I work even harder to solve it.	.15	**.72**	.08	-.19	-.07	-.05
EC(4)	I can spend hours on a single problem because I just can't rest without knowing the answer.	.10	**.70**	.07	-.16	-.07	.08
EC(10)	I work like a fiend at problems that I feel must be solved.	-.11	**.64**	.16	.05	.00	-.02
EC(8)	I brood for a long time in an attempt to solve some fundamental problem.	-.09	**.58**	.14	.00	-.02	.15
EC(2)	Difficult conceptual problems can keep me awake all night thinking about solutions.	-.10	**.57**	.15	-.12	-.02	.04
EC(7)	When I learn something new, I would like to find out more about it.	.05	**.42**	-.01	.00	.06	.18
NFC(18)	I usually end up deliberating about issues even when they do not affect me personally.	-.06	**.38**	.05	**.33**	.01	-.10
TIE(8)		**-.22**	**.37**	.01	.01	.10	.12
TIE(28)		**.22**	**-.35**	**.29**	.13	.04	.08
TIE(40)		.13	**.34**	-.03	**.21**	.07	.04
TIE(10)		-.10	**.34**	-.04	**.31**	.06	-.10
TIE(30)		**.24**	**.33**	-.09	.13	.07	-.08
TIE(58)		.10	**.33**	**-.26**	**.28**	-.07	.14
EC(3)	I enjoy learning about subjects that are unfamiliar to me.	.15	**.23**	.13	.05	.20	.13
TIE(59)		.18	**.22**	.03	.16	.06	-.11
TIE(21)		.13	**-.21**	.04	.10	.05	.15

TIE(23)		.06	.16	.10	-.08	.09	.01
NFC(13)	I prefer my life to be filled with puzzles I must solve.	-.07	.07	**.77**	-.01	.07	-.01
TIE(18)		-.14	.07	**.69**	-.04	-.01	.14
TIE(43)		.15	.10	**.67**	-.05	.04	-.05
TIE(35)		.07	**.21**	**.62**	.10	-.01	-.10
NFC(2)	I like to have the responsibility of handling a situation that requires a lot of thinking.	.08	**.20**	**.58**	.00	-.13	.10
NFC(1)	I prefer complex to simple problems.	.15	**.26**	**.56**	-.06	.02	-.07
NFC(15)	I would prefer a task that is intellectual, difficult, and important to one that is somewhat important but does not require much thought.	.07	.19	**.44**	.13	.08	-.06
NFC(11)	I really enjoy a task that involves coming up with new solutions to problems.	.06	.17	**.42**	.18	-.06	.15
NFC(6)	I find satisfaction in deliberating hard and for long hours.	-.01	.12	**.41**	.11	-.03	.13
TIE(56)		-.01	.15	**.39**	.17	-.10	**.28**
NFC(16)	I feel relief rather than satisfaction after completing a task that requires a lot of mental effort.	**.33**	-.12	**.36**	.00	.06	-.12
TIE(34)		-.16	**.31**	**.34**	.16	-.01	-.05
TIE(2)		.06	**.24**	**-.33**	**.27**	-.07	**.28**
TIE(26)		-.14	.01	**.28**	.12	.09	-.06
NFC(14)	The notion of thinking abstractly is appealing to me.	-.09	-.09	**.30**	**.81**	-.02	-.08
TIE(16)		.13	-.17	.03	**.80**	.01	-.03
EC(9)	I enjoy discussing abstract concepts.	-.07	-.01	.15	**.77**	-.03	-.04
TIE(3)		-.06	.00	-.06	**.67**	.03	.11
TIE(44)		**.43**	-.08	-.07	**.54**	-.07	-.16
TIE(29)		-.09	.08	.16	**.40**	.00	-.05
TIE(39)		-.01	**.21**	.06	**.37**	-.01	.02
NFC(10)	The idea of relying on thought to make my way to the top appeals to me.	.09	.13	**.23**	**.29**	-.02	.03
EC(1)	I enjoy exploring new ideas.	.13	.19	.06	**.27**	.01	**.20**
TIE(24)		.15	-.05	-.13	**.25**	-.07	.12
TIE(19)		.15	-.08	.11	**.24**	-.05	.00

TIE(22)	.02	.00	-.11	-.05	**.85**	.01
TIE(50)	.04	-.05	.01	-.01	**.84**	-.14
TIE(41)	-.04	-.08	.07	.01	**.75**	**.24**
TIE(14)	.09	.01	.11	-.03	**.71**	-.05
TIE(38)	-.10	-.02	.00	-.01	**.70**	.09
TIE(37)	-.05	.07	.02	-.05	**.69**	-.02
TIE(33)	-.03	.09	.13	.11	**.33**	-.15
TIE(46)	.13	.08	.17	.04	**.24**	.17
TIE(55)	-.05	-.02	**.20**	.04	-.11	**.57**
TIE(15)	-.08	.11	-.13	.11	-.02	**.53**
TIE(27)	-.06	.10	.16	-.08	-.02	**.47**
TIE(5)	-.16	-.11	-.19	**.34**	.01	**.45**
TIE(1)	.01	.09	-.07	-.12	-.03	**.43**
TIE(11)	-.08	.09	.13	.13	.06	**.43**
TIE(25)	.06	.01	.10	-.07	.18	**.39**
TIE(17)	.11	-.17	**.23**	-.02	.00	**.37**
TIE(53)	-.15	.12	.12	-.16	.01	**.30**
TIE(32)	.04	.04	.17	-.08	.10	**.26**

Note. Factor loadings >= .20 are in boldface. NFC = Need for Cognition; TIE = Typical Intellectual Engagement; EC = Epistemic Curiosity; *IA = Intellectual Avoidance*; *D = Deprivation*; *PS = Problem Solving*; *AT = Abstract Thinking*; *R = Reading*; *WI = Wide Interest*.

*TIE items are not available due to copyright, but can be requested from Professor Phillip Ackerman.

Appendix 2

Study 1: Factor loadings for exploratory factor analysis with promax rotation and Schmid-Leiman rotation for intellectual curiosity items

Scale and item number	Item*	*G*	*IA*	*D*	*PS*	*AT*	*R*	*WI*	H² total	H² G	H² first order
NFC (17)	It's enough for me that something gets done. I don't care why or how.	.65	**.36**	.01	-.03	.04	.00	-.05	56%	43%	14%
TIE (7)		.52	**.36**	.00	-.02	.00	-.02	-.12	41%	27%	14%
TIE (6)		.51	**.33**	.04	-.03	.02	-.02	-.13	39%	26%	13%
TIE (42)		.61	**.32**	.09	-.10	.05	-.04	.05	50%	37%	13%
TIE (9)		.45	**.31**	.15	-.06	-.12	-.01	-.04	34%	20%	13%
NFC (4)	I would rather do something that requires little thought than something that is sure to challenge my thinking abilities.	.76	**.31**	-.03	.13	-.02	.04	-.01	70%	58%	11%
TIE (13)		.61	**.29**	-.05	.05	.03	.06	-.06	47%	38%	10%
TIE (49)		.38	**.29**	-.03	-.02	-.05	-.11	.03	24%	14%	10%
NFC (5)	I try to anticipate and avoid situations where there is a likely chance I will have to think in depth about something.	.72	**.29**	-.09	.10	.04	.04	.03	62%	51%	10%
NFC (3)	Thinking is not my idea of fun.	.68	**.25**	-.02	.01	.06	.01	.14	55%	46%	9%
TIE (12)		.65	**.25**	.04	-.06	.05	-.01	**.22**	54%	42%	12%
NFC (12)	Learning new ways to think doesn't excite me very much.	.74	**.24**	.02	.01	.11	-.01	.12	63%	54%	9%
TIE (48)		.43	**.24**	.01	.01	-.14	.05	.11	28%	19%	9%
NFC (7)	I only think as hard as I have to.	.64	**.23**	-.09	.13	.05	.03	.01	49%	41%	8%
NFC (9)	I like tasks that require little thought once I've learned them.	.53	**.23**	-.08	.18	-.15	-.03	.10	41%	29%	12%
TIE (52)		.55	**.21**	-.02	.18	-.06	-.12	.02	40%	30%	10%
NFC (8)	I prefer to think about small daily projects to long term ones.	.42	**.21**	.00	-.01	.00	.03	.03	22%	18%	4%
EC (6)	I feel frustrated if I can't figure out the solution to a problem, so I work even harder to solve it.	.50	.07	**.49**	.04	-.12	-.06	-.04	52%	25%	27%

EC (4)	I can spend hours on a single problem because I just can't rest without knowing the answer.	.55	.05	**.48**	.03	-.10	-.06	.06	55%	30%	25%
EC (10)	I work like a fiend at problems that I feel must be solved.	.53	-.05	**.44**	.08	.03	.00	-.02	49%	28%	21%
EC (8)	I brood for a long time in an attempt to solve some fundamental problem.	.55	-.04	**.40**	.07	.00	-.02	.11	48%	30%	18%
EC (2)	Difficult conceptual problems can keep me awake all night thinking about solutions.	.38	-.05	**.39**	.07	-.07	-.02	.03	31%	15%	17%
EC (7)	When I learn something new, I would like to find out more about it.	.49	.02	**.29**	-.01	.00	.05	.14	35%	24%	11%
NFC (18)	I usually end up deliberating about issues even when they do not affect me personally.	.47	-.03	**.26**	.03	**.20**	.01	-.08	34%	22%	12%
TIE (8)		.23	-.10	**.25**	.00	.01	.08	.09	14%	5%	9%
TIE (28)		.37	.10	**-.24**	.14	.08	.04	.06	23%	14%	10%
TIE (40)		.56	.06	**.23**	-.02	.13	.06	.03	39%	32%	8%
TIE (10)		.33	-.05	**.23**	-.02	.19	.05	-.07	21%	11%	10%
TIE (30)		.46	.11	**.23**	-.05	.08	.06	-.06	29%	21%	8%
TIE (58)		.37	.05	**.22**	-.13	.17	-.06	.11	25%	14%	11%
TIE (34)		.46	-.08	**.21**	.17	.10	-.01	-.04	31%	22%	9%
NFC (13)	I prefer my life to be filled with puzzles I must solve.	.68	-.03	.05	**.39**	-.01	.06	-.01	61%	46%	16%
TIE (18)		.58	-.07	.05	**.35**	-.02	-.01	.11	47%	33%	14%
TIE (43)		.73	.07	.07	**.33**	-.03	.04	-.04	65%	53%	13%
TIE (35)		.76	.03	.14	**.31**	.06	-.01	-.07	70%	57%	13%
NFC (2)	I like to have the responsibility of handling a situation that requires a lot of thinking.	.71	.04	.14	**.29**	.00	-.11	.08	63%	51%	12%
NFC (1)	I prefer complex to simple problems.	.73	.07	.18	**.28**	-.03	.02	-.05	65%	53%	12%
NFC (15)	I would prefer a task that is intellectual, difficult, and important to one that is somewhat important but does not require much thought.	.70	.03	.13	**.22**	.08	.07	-.04	57%	49%	8%
NFC (11)	I really enjoy a task that involves coming up with new solutions to problems.	.75	.03	.12	**.21**	.11	-.05	.12	66%	57%	9%

NFC (6)	I find satisfaction in deliberating hard and for long hours.	.58	-.01	.08	**.20**	.07	-.03	.10	40%	34%	6%
NFC (14)	The notion of thinking abstractly is appealing to me.	.69	-.04	-.06	.15	**.51**	-.02	-.06	77%	48%	29%
TIE (16)		.63	.06	-.12	.02	**.49**	.01	-.02	66%	40%	26%
EC (9)	I enjoy discussing abstract concepts.	.62	-.03	-.01	.07	**.48**	-.02	-.03	62%	38%	24%
TIE (3)		.51	-.03	.00	-.03	**.41**	.03	.08	44%	26%	18%
TIE (44)		.54	.20	-.05	-.04	**.33**	-.06	-.12	46%	29%	17%
TIE (29)		.40	-.04	.06	.08	**.25**	.00	-.03	24%	16%	7%
TIE (39)		.49	-.01	.15	.03	**.23**	-.01	.01	32%	24%	8%
TIE (45)		.55	.17	.03	.03	**.22**	-.05	-.11	40%	31%	9%
TIE (22)		.37	.01	.00	-.05	-.03	**.70**	.00	63%	13%	50%
TIE (50)		.38	.02	-.03	.00	-.01	**.70**	-.11	64%	14%	50%
TIE (41)		.55	-.02	-.06	.03	.01	**.62**	.18	72%	30%	42%
TIE (14)		.52	.04	.00	.06	-.02	**.58**	-.04	62%	27%	35%
TIE (38)		.34	-.05	-.01	.00	-.01	**.58**	.07	46%	12%	34%
TIE (37)		.35	-.02	.05	.01	-.03	**.57**	-.02	46%	12%	33%
TIE (33)		.32	-.01	.06	.06	.07	**.28**	-.12	20%	10%	10%
TIE (57)		.41	.17	.02	-.06	.07	**.21**	-.07	26%	17%	9%
TIE (55)		.46	-.02	-.01	.10	.02	-.09	**.43**	42%	21%	21%
TIE (15)		.32	-.04	.07	-.06	.07	-.02	**.40**	28%	10%	18%
TIE (27)		.40	-.03	.07	.08	-.05	-.02	**.35**	30%	16%	14%
TIE (5)		.19	-.07	-.08	-.10	**.21**	.01	**.34**	22%	4%	18%
TIE (1)		.19	.01	.06	-.04	-.07	-.03	**.33**	15%	4%	12%
TIE (11)		.52	-.04	.07	.07	.08	.05	**.32**	40%	28%	12%
TIE (25)		.45	.03	.01	.05	-.04	.15	**.30**	32%	20%	12%
TIE (17)		.40	.05	-.12	.11	-.01	.00	**.28**	27%	16%	11%
TIE (53)		.14	-.07	.08	.06	-.10	.01	**.22**	9%	2%	8%
TIE (36)		.38	**.21**	.12	.03	-.01	-.01	**-.22**	25%	14%	11%
TIE (56)		.71	.00	.10	.20	.11	-.08	**.21**	61%	50%	11%

TIE (2)		.29	.03	.16	-.17	.17	-.06	**.21**	21%	8%	13%
TIE (54)		.39	.16	-.06	.02	-.02	-.08	**.20**	23%	15%	8%
EC (5)	I find it fascinating to learn new information.	.67	.14	.20	-.02	.08	.08	.10	53%	45%	8%
EC (1)	I enjoy exploring new ideas.	.64	.06	.13	.03	.17	.01	.15	48%	41%	7%
EC (3)	I enjoy learning about subjects that are unfamiliar to me.	.64	.07	.16	.06	.03	.17	.10	48%	41%	7%
NFC (10)	The idea of relying on thought to make my way to the top appeals to me.	.60	.04	.09	.11	.18	-.01	.03	42%	36%	5%
TIE (46)		.59	.06	.05	.09	.03	.20	.13	42%	35%	7%
NFC (16)	I feel relief rather than satisfaction after completing a task that requires a lot of mental effort.	.47	.15	-.08	.18	.00	.05	-.09	29%	22%	7%
TIE (59)		.43	.09	.15	.01	.10	.05	-.08	24%	19%	5%
TIE (51)		.39	.16	-.12	.11	.00	-.08	.08	21%	15%	6%
TIE (32)		.38	.02	.03	.09	-.05	.08	.20	20%	15%	6%
TIE (47)		.36	.18	.07	.00	-.03	.02	-.02	16%	13%	4%
TIE (4)		.35	.12	.05	-.08	.02	.10	.14	18%	12%	5%
TIE (19)		.33	.07	-.06	.06	.15	-.04	.00	14%	11%	4%
TIE (23)		.25	.03	.11	.05	-.05	.07	.01	9%	6%	2%
TIE (26)		.23	-.07	.01	.14	.07	.07	-.04	9%	5%	4%
TIE (24)		.22	.07	-.03	-.07	.15	-.06	.09	10%	5%	5%
TIE (21)		.20	.06	-.14	.02	.06	.04	.11	8%	4%	4%
TIE (20)		.20	.10	-.09	.00	.07	.01	-.01	6%	4%	2%
TIE (31)		.16	.13	.00	-.06	.01	.08	-.03	5%	3%	3%

Note. Factor loadings > .20 are in boldface. NFC = Need for Cognition; TIE = Typical Intellectual Engagement; EC = Epistemic Curiosity; *G = General curiosity factor; IA = Intellectual Avoidance; D = Deprivation; PS = Problem Solving; AT = Abstract Thinking; R = Reading; WI = Wide Interest*; H^2 total = percentage of item-level variance explained by general and first order factors; H^2 total = percentage of item-level variance explained by the general factor; H^2 first order = percentage of item-level variance explained by the first order factor.

*TIE items are not available due to copyright, but can be requested from Professor Phillip Ackerman.

Appendix 3

Study 1: Factor correlation matrix for the six factors

Factor	*A*	*D*	*PS*	*AT*	*R*	*WI*
Avoidance (A)	1					
Deprivation (D)	.44	1				
Problem Solving (PS)	.62	.50	1			
Abstract Thinking (AT)	.60	.49	.50	1		
Reading (R)	.41	.34	.39	.36	1	
Wide Interest (WI)	.41	.43	.49	.39	.34	1

Note. All correlations are significant to $p < .01$, 2-tailed.