Grit and Self-Discipline as Predictors of Effort and Academic Attainment

Martin S. Hagger[a,b,c], Kyra Hamilton[a,b]

[a]Laboratory of Self-Regulation and Health Psychology and Behavioural Medicine Research Group, School of Psychology, Faculty of Health Sciences, Curtin University, Perth, Australia email: martin.hagger@curtin.edu.au
[b]School of Applied Psychology and Menzies Health Institute Queensland, Griffith University, Brisbane, Australia, kyra.hamilton@griffith.edu.au
[c]Faculty of Sport and Health Sciences, University of Jyväskylä, Jyväskylä, Finland

Acknowledgements. Martin S. Hagger's contribution was supported by a Finland Distinguished Professor (FiDiPro) award (Dnro 1801/31/2105) from Business Finland. We thank Clair Alston-Knox for her advice on the data analysis.

Correspondence to: Martin S. Hagger, Laboratory of Self-Regulation and Health Psychology and Behavioural Medicine Research Group, School of Psychology, Faculty of Health Sciences, Curtin University, GPO Box U1987, Perth, WA6845, Australia, tel: +61 8 92662215, fax: +61 8 92662464, email: martin.hagger@curtin.edu.au

Full citation: Hagger, M. S., & Hamilton, K. (2018). Grit and self-discipline as predictors of effort and academic attainment. *British Journal of Educational Psychology*. doi: 10.1111/bjep.12241

Abstract

Background. Beyond ability, traits related to perseverance, such as grit and self-discipline, are associated with adaptive educational outcomes. Few studies have examined the independent effects of these traits on outcomes and the mechanisms involved.

Aims. The present study estimated parameters of a process model in which grit perseverance of effort (grit-effort) and consistency of interest (grit-interest) dimensions and self-discipline were independent predictors of students' science grades. The effect of the grit-effort on grades was expected to be mediated by students' self-reported effort on optional out-of-school science learning activities.

Sample. Secondary school students (N=110) aged between 12 and 14 years.

Methods. The study adopted a correlational design with measures taken on three occasions. Students completed self-report measures of grit and self-discipline early in the semester and effort on optional out-of-school learning activities five weeks later. Students' science grades were collected at the end of the semester. Data were analysed using Bayesian path analyses using non-informative and informative priors derived from previous research.

Results. Consistent with predictions, we found effects of grit-effort on science grades mediated by effort, and self-discipline on grades. Contrary to predictions, we also found an effect of self-discipline on grades mediated by effort. Zero was a credible value for direct effects of grit-effort on grades, and grit-interest on effort and grades.

Conclusions. Results suggest grit-effort and self-discipline relate to effort on educational activities linked to better grades. The direct effect of self-discipline on grades suggests that it may be related to other activities that determine science attainment.

Key words: perseverance of effort; consistency of interest; self-control; science education; goal conflict; Bayesian path analysis

Introduction

Researchers examining the antecedents of academic attainment have tended to focus on two sets of factors; those related to ability (e.g., general intelligence, executive functioning) and those related to perseverance (e.g., motivation, personality). The literature on intellectual traits as predictors of attainment is vast (e.g., Kuncel, Hezlett, & Ones, 2004; Rohde & Thompson, 2007), while research on perseverance factors has tended to lag behind by comparison (Duckworth & Seligman, 2005). Nevertheless, a growing literature demonstrates the pervasive effect of factors relating to perseverance on academic attainment (Dumfart & Neubauer, 2016; Richardson, Abraham, & Bond, 2012). Prominent among these factors are traits that determine long term persistence on tasks to attain distal goals, such as self-discipline and grit (Duckworth, Matthews, & Kelly, 2007; Duckworth & Seligman, 2005). Both of these factors have been associated with adaptive outcomes in educational contexts (Duckworth et al., 2007; Duckworth & Seligman, 2005; Zimmerman & Kitsantas, 2014). While research has indicated that self-discipline, and allied traits such as self-control and conscientiousness, and grit are strongly correlated (Credé, Tynan, & Harms, 2017; Duckworth et al., 2007; Oriol, Miranda, Oyanedel, & Torres, 2017), there has been a recent focus on their conceptual and empirical distinction, and discussion over the extent to which they may differentially determine outcomes (Duckworth & Gross, 2014). However, to date, few studies have examined the independent effects of these factors on outcomes and none have tested the mechanisms involved. The current research aimed to estimate parameters of a process model in which self-discipline and grit were proposed as independent predictors of science grades in a sample of secondary school students. In addition, the effect of grit on grades was proposed to be mediated by students' self-reported effort on science learning activities. The research is expected to advance knowledge of the effect of perseverance factors on academic attainment, and role of effort as a key process variable.

Self-Discipline and Grit

Self-discipline and grit are individual difference variables associated with effortful perseverance on goal-directed tasks. Self-discipline has received considerable attention in the scientific literature as a sub-facet of the conscientiousness personality trait (Poropat, 2009). The construct is conceptualised as an individual's capacity to suppress or inhibit prepotent or dominant responses in favour of an alternative action that is strategic and services a long-term or higher-order goal (Allom, Panetta, Mullan, & Hagger, 2016; Tangney, Baumeister, & Boone, 2004). Self-discipline is closely aligned with similar constructs such as trait self-control (Duckworth & Kern, 2011; Dumfart & Neubauer, 2016; Zimmerman & Kitsantas, 2014). From a mechanistic perspective, individuals with high self-discipline are expected to be able to effectively manage conflicts between momentary impulse-driven goals with small, gratifying short-term gains and long-term goals with larger gains that require greater effort and persistence (Duckworth & Gross, 2014; Gottfredson & Hirschi, 1990; Tangney et al., 2004). People with high self-discipline are also able to employ a number of strategies to help them manage situations where they may succumb to impulse-driven responses (Friese, Hofmann, & Wiers, 2011; Quinn, Pascoe, Wood, & Neal, 2010; Trope & Fishbach, 2000). Research has demonstrated that self-discipline is associated with better academic performance even when controlling for measures of ability such as intelligence (Duckworth & Seligman, 2005).

Grit is a recently-developed construct defined as "trait-level perseverance and passion for long-term goals" (Duckworth & Quinn, 2009, p. 168). Grit is, therefore, conceptualised in terms of sustained motivation, effort, and interest on tasks to achieve long-term goals. It has been proposed as distinct from self-discipline and other components of conscientiousness through its focus on sustained effort and focus on specific long-term goals, even in the face of failure, and the absence of positive feedback or goal progress (Lucas, Gratch, Cheng, & Marsella, 2015; Zimmerman & Kitsantas, 2014). From a mechanistic perspective, 'gritty' individuals are likely to invest considerable sustained effort on, and retain interest in, tasks and behaviours required to attain long-term goals (Bowman, Hill, Denson, & Bronkema, 2015;

Duckworth, Kirby, Tsukayama, Berstein, & Ericsson, 2011; Silvia, Eddington, Beaty, Nusbaum, & Kwapil, 2013). For example, studies have demonstrated that individuals with higher scores on grit scales are more likely to engage in deliberate practice on tasks, which mediates the effect of grit on long-term achievement-related outcomes (Duckworth et al., 2011).

Duckworth and Gross (2014) provide a conceptual basis for grit and self-discipline as distinct constructs. They propose that self-discipline relates to individuals' capacity to regulate actions and inhibit prepotent responses at a subordinate goal level, such as a generalised capacity to resist the temptation to eat palatable but unhealthy foods when on a diet. Such actions require effortful engagement to resolve conflict between goal-directed behaviours. Grit on the other hand relates to focused engagement in goal-directed action to attain higher-order, long term goals and to structure behavioural efforts toward those goals accordingly. Gritty individuals are therefore apt at engaging in focused recruitment of resources and actions to resolve multiple goal conflicts over extended periods.

Two independent dimensions of grit have been identified, perseverance of effort (grit-effort) and consistency of interest (grit-interest). Research has indicated that the grit dimensions achieve discriminant and predictive validity (Bowman et al., 2015; Duckworth & Quinn, 2009). Consistent with the distinction, effort and sustained interest are expected to be candidate mediators of the effects of the grit-effort and grit-interest dimensions, respectively, on long-term outcomes.

A recent meta-analysis of research examining effects of grit on key outcomes, including student performance in education contexts, alongside related traits such as conscientiousness and self-control, raised some questions over the two-factor structure of the construct, its predictive validity, and its discriminant validity with conscientiousness (Credé et al., 2017). Credé et al. (2017) demonstrated that combining grit-interest with grit-effort in an overall grit score resulted in substantive loss in predictive validity of the construct, and that the grit-effort

construct had the greatest utility in predicting academic-related outcomes. They also suggested that the overall grit construct may not achieve discriminant validity from conscientiousness, but found that the grit-effort dimension predicted unique variance in academic outcomes independent of conscientiousness. They also revealed large correlations between overall grit and self-control, but did not report separate relations between grit-effort and this construct. Overall, the researchers concluded that the grit-effort component is the most useful component of grit and may have utility in determining academic performance alongside traits related to conscientiousness.

A Process Model of Self-Discipline and Grit

Duckworth and Gross' (2014) framework suggests that individuals with high self-discipline will be effective in managing specific instances requiring response inhibition and resolution of goal conflict, and may be useful in day-to-day management of goal conflicts. In contrast, they suggest that attaining long-term adaptive outcomes such as attaining a high grade in an exam, losing weight, or gaining promotion at work requires grit. Accordingly, we propose a set of predictions derived from their framework in a model that outlines the processes by which self-discipline and grit impact long-term outcomes. We propose to test this model in high-school students' academic attainment in science represented by their aggregate end-of-semester grades. Our model is outlined in Figure 1 and the accompanying set of predicted effects, segregated into direct and indirect effects, are outlined in Table 1. Next we outline each predicted effect and its conceptual basis.

Prior research has indicated that 'gritty' individuals are more likely to engage in focused practice toward a singular, long-term outcome with a comparatively large 'payoff'. Consistent with this premise, we predict that the effect of grit on students' science grades will be mediated by the self-reported effort they invest in activities likely to relate to attaining long-term success in science. In the current study this is manifested in students' self-reported effort on optional out-of-school science learning activities set by their teacher. Students' reports of

their engagement in such activities is assumed to reflect the kind of focused practice suggested to attain long-term educational goals (Duckworth et al., 2011). We also make the assumption that self-reports of trying hard on out-of-school learning activities would reflect actual effort on the activities, from which we infer the mediating role that effort plays in the relationship between grit and academic attainment. However, this assumption would need confirmation through measures of actual effort. In addition, research testing the multidimensionality of the grit construct, has shown stronger, more consistent effects of the grit-effort dimension on academic outcomes relative to the grit-interest dimension (Bowman et al., 2015; Credé et al., 2017).

Given this previous research, we predict that the grit-effort dimension will have a positive non-zero direct effect on students' self-reported effort on optional out-of-school science learning activities (represented by path P_1, in Table 1 and Figure 1), and effort on the learning activities will be related to students' science grades (P_7). Consistent with the proposed process, we predict that the effect of grit-effort on grades will be mediated by effort (P_{11}). In contrast, we propose that the effect of grit-interest on effort (P_2) would be zero, consistent with research demonstrating weak or null effects for this dimension on outcomes (Bowman, Gortmaker, Ebbeling, Pereira, & Ludwig, 2004) and issues surrounding its validity (Credé et al., 2017). We therefore expect the indirect effect of grit-interest on grades through effort to be zero (P_{12}). Consistent with the mediation predictions, we expect the direct effects of grit-effort (P_4) and grit-interest (P_5) on science grades to be zero. As self-discipline reflects individuals' capacity to manage individual goal conflicts, we predict that it will be implicated in the attainment of long-term goals, but the effects may not be mediated by effort on activities aimed at bringing about the outcome. We therefore propose a direct effect of self-discipline on students' science grades (P_6). Research has also linked self-discipline with effort, so we propose to include this effect in our model (P_3), but propose that zero will be a plausible value

for the indirect effect of self-discipline on grades through effort (P_{13}). Finally, we expect the grit-effort, grit-interest, and self-discipline constructs to be positively related (P_8-P_{10}).

A Bayesian Approach to the Process Model

Although there is no research to date that has simultaneously examined relations among grit, self-discipline, self-reported effort, and long-term educational outcomes consistent with our proposed process model, there is research supporting individual relations among the component constructs (e.g., Credé et al., 2017; Duckworth & Seligman, 2005; Meriac, Slifka, & LaBat, 2015; Richardson et al., 2012). The research provides useful reference data for the proposed effects in the process model against which new observations can be compared. By adopting a Bayesian analytic approach we aim to incorporate this existing knowledge into the test of our process model in the form of informative 'prior' values. In doing so, the analysis will provide updated estimates of the proposed relations among model constructs, and, importantly, the distribution of possible values of the effects based on the priors and new observations (van de Schoot et al., 2014; Zyphur & Oswald, 2015).

The Bayesian analytic approach is important because it enables us to evaluate our proposed model against prior tests of model effects, even though the parameters of the model have not been previously estimated. We will derive informative priors from previous research testing the component effects of the model independently and evaluate them against our observations in the Bayesian analysis. If our priors are a good representation of the true model effects and their distributions, then the posterior distributions of the model parameter estimates from the Bayesian analysis will be reduced and the estimates more precise. If the priors are a poor representation, the analysis will yield less precise, highly variable posterior distributions for the model parameters. The posterior distribution of the model estimates will be represented by 95% credible intervals about the parameter estimates. Consistent with the parameter estimation approach in Bayesian analysis (Rouder, Haaf, & Vandekerckhove, 2018), we aim to

provide the most precise estimates possible of the effects among constructs in our proposed model given a set of empirically-informed prior values and our data.

The Current Study

The purpose of this study was to estimate the effects of grit dimensions, self-discipline, and self-reported effort on optional out-of-school science activities and science grades, as proposed in our process model in a sample of high school students. The study is expected to provide evidence of the processes by which grit, particularly grit-effort, and self-discipline relate to science attainment based on Duckworth and Gross' (2014) goal framework. We focus on teacher-set out-of-school learning activities because engagement in these activities is likely to broaden and deepen students' understanding and contribute to academic attainment. We focus on science attainment due to the documented shortfall in students selecting science and maths in high school and tertiary education (NCES, 2012; Thomson, Wernert, O'Grady, & Rodrigues, 2016). Science education has been identified as an important driver of economic growth in many nations, so knowledge of the correlates science engagement may inform science education policy and interventions. Consistent with the parameter estimation approach from Bayesian analyses (Rouder et al., 2018), we aim to provide the most precise estimates possible of model effects and their distribution from the current data by incorporating observations from previous research on relations among individual model effects as informative priors (Bowman et al., 2015; Duckworth & Seligman, 2005; Meriac et al., 2015; Richardson et al., 2012; Wolters & Hussain, 2015). We will use the credible intervals based on the posterior distribution about the parameter estimates to evaluate whether or not zero is a credible value for each model effect.

Methods

Participants

School students (N = 117; girls n = 59; boys, n = 58) were recruited from a coeducational government secondary school in metropolitan Brisbane, Australia. Students were aged between

12 and 14 years and in school grades 7, 8, and 9. General demographic characteristics of the school catchment area and student population were obtained from the school's annual report and the *My School* website (http://www.myschool.edu.au/). The majority of students were born in Australia, with most of the students' parents reported employment in technical and trade occupations, with a few employed in administrative and professional jobs. The index of community socio-educational advantage (ICSEA), a scale of socioeducational advantage that is computed for each school across Australia, for the school was just below the national average (ACARA, 2016).

Research design

The University ethics committee and local educational authority approved the study prior to data collection. The study adopted a correlational three-wave design as part of a larger study on individual differences and educational attainment. Participants completed a survey mid-semester comprising self-report measures of grit, self-discipline, and demographic variables. Five-weeks later they self-reported their effort on optional out-of-school science learning activities set by their science teacher. Students' final end-of-semester science grades comprising their averaged mark across all in-class science assignments for the semester were collected from their teacher.

Measures

Grit. Students completed the eight-item short grit scale (Duckworth & Quinn, 2009). The scale comprises two subscales, perseverance of effort (grit-effort; e.g., "I finish whatever I begin") and consistency of interest (grit-interest; e.g., "I often set a goal but later choose to pursue a different one"). Responses were provided on 5-point scales (1 = *not like me at all* and 4 = *very much like me*).

Self-discipline. Students completed the self-discipline scale derived from the International Personality Item Pool HEXACO scales (Ashton, Lee, & Goldberg, 2007). The

scale comprises ten items (e.g., "I have difficulty starting tasks") of which five are reverse scored. Reponses were provided on 5-point scales (1 = *not at all* and 5 = *very much*).

Effort. Students' self-reported effort on optional out-of-school science learning activities set by their science teacher was measured on five items (e.g., "During the last 5 weeks, how hard did you try to do your science activities at home?") with responses made on 7-point scales (1 = *did not try at all* and 7 = *tried extremely hard*). Prior to completing these items, students were reminded that "science learning activities" referred to the "assignments you are given by your teacher in science lessons for you to do outside of school such as solving science problems, writing up science experiments, science activities on the internet, and studying for science exams"[1]. We focused on effort toward out-of-school science learning activities set by the teacher because such activities are aimed at supporting the school curriculum and students engaging these activities are likely to report better retention of knowledge and skills learned in class (Trautwein, Ludtke, Kastens, & Koller, 2006; Zimmerman & Kitsantas, 2005).

Academic attainment. Students' averaged final semester science grade, calculated as the mean average of grades on in-school science assignments, was collected at the end of the semester from their science teacher. The grade represented the average grade across all coursework, two class tests, and final examination for the semester expressed as a percentage.

Full details of measures used in the current study are provided in the Supporting Information (Appendix A).

Data Analysis

Data were analyzed using Bayesian path analysis using the Mplus 7.31 statistical software (Muthén & Muthén, 2015). Psychological constructs were manifest variables

[1]It is important to note that the out-of-school learning activities in the current study should not be considered formal assessed homework. Students did not receive formal assessed homework for science. Instead, they were provided with regular learning activities by their science teacher to complete in their spare time outside of school. Engagement in the activities was not compulsory. Teachers would refer to these activities in subsequent lessons, but not evaluate whether or not students had performed the activities.

computed from the mean of the scale items pertaining to each construct. Proposed direct and indirect effects among the grit, self-discipline, self-reported effort, and grades variables in the proposed model summarised in Table 1 and Figure 1 were set as free parameters in the model. We controlled for effects of age and gender by setting them to predict all other variables in the model. Bayesian path analyses were estimated using a Markov Chain Monte Carlo (MCMC) simulation process using Gibbs' algorithms (Muthén & Asparouhov, 2012). We specified 100,000 iterations of which the first half were used as a 'burnin' phase and the remaining posterior draws used to estimate model inferences. We adopted the Gelman and Rubin's (1992) criterion to determine the convergence of the Bayesian estimates with a strict potential scale reduction (PSR) value of 1.01. Two models were estimated. The first was estimated using non-informative prior values for model parameters using the standard default values offered in the Mplus software for regression analysis: each parameter estimate is assigned a prior that specifies a normal distribution with mean = 0 and variance = infinity[2]. Estimating the Bayesian model using these default priors will return estimates close to an analysis using a frequentist analytic method such as maximum likelihood.

The second adopted informative prior values for key parameters in the model derived from previous research. While our process model has not been tested previously, its component effects have been estimated in separate research studies. Priors were identified from a search of previous studies testing relations between grit, self-discipline, self-reported effort, and academic attainment. Our informative priors were derived from meta-analytic and primary research testing relations among constructs in our proposed model in samples with a close match to the current sample and context (secondary school pupils). Prior values expressed as correlation coefficients, associated variance estimates expressed as standard deviations, and source data for the values are summarised in Table 1. In cases where the standard deviations of

[2]In this case the variance is set at a number sufficiently large to approximate infinity. According to Muthén & Muthén (2012), "for the normal distribution default, infinity is ten to the power of ten" (p. 698).

the correlations were unspecified, non-restrictive weakly-informative prior variance estimates were specified (SD = 0.10) to account for possible heterogeneity between current data and the studies used as sources for the priors (Yuan & MacKinnon, 2009). We could not identify studies reporting relations between self-discipline and the separate perseverance of effort and consistency of interest grit dimensions. However, there were several tests of the total grit scale and self-discipline (Credé et al., 2017; Dumfart & Neubauer, 2016; Oriol et al., 2017), so we used the median value from these studies as prior values for relations between grit-effort and grit-perseverance with self-discipline.

Fit of the Bayesian models was assessed using posterior predictive checking using two recommended criteria based on the usual goodness-of-fit chi-square comparing the proposed model with the observed data across the replications in the Bayesian simulation (Gelman et al., 2013): (a) the 95% confidence intervals (CI_{95}) of the chi-square value, which should include zero and have a large negative lower bound, and (b) the posterior predictive *p*-value (PPP), which should exceed .05 and preferably approach .50 for a well-fitting model. For each free parameter in the Bayesian model, a credible interval (CrI) is computed which should exclude the value of zero to indicate a true effect. We also generated estimates of indirect effects in the Bayesian models using Yuan and MacKinnon's (2009) method. If, as expected, the prior distributions of model parameters were closely representative of population effects, we anticipated that the path model adopting informative priors would exhibit increased precision in model parameter estimates, as indicated by narrowed credible intervals about each parameter. The effect of specifying empirically-determined informative priors on the variability of model parameter estimates was evaluated by examining the extent to which the width of the credible intervals for each parameter decreased across the models with informative and non-informative priors[3].

Results

[3]Mplus analysis scripts and output are available from https://osf.io/2nzpx/

Participants

There was minimal attrition across the two data collection occasions (n = 7) resulting in a final sample size of 110 (girls = 55, boys = 55; *M* age = 12.80, SD = 0.72). Descriptive statistics, omega reliability coefficients (McNeish, 2017), and intercorrelations for study variables are presented in Table 2.

Bayesian Path Analyses

The Bayesian path analyses with non-informative (PPP = .464, 95% CrI [-21.56, 24.20]) and informative priors (PPP = .370, 95% CrI [-18.31, 26.99]) exhibited satisfactory goodness-of-fit with the data according to the posterior predictive checking criteria. Parameter estimates for the analyses with non-informative priors and informative priors are provided in Table 3, and illustrated in Figures 1a and 1b. The path model adopting informative priors resulted in a narrowing of the credible intervals about all model parameter estimates, as indicated by the percentage change in the intervals across the models (Yuan & MacKinnon, 2009). This suggests that the data and the prior distribution were closely matched. We therefore report the effects for the model with informative priors. Credible intervals associated with parameter estimates reflect the posterior distribution of probable values for the parameter and whether zero is a credible value based on the prior and sampling distributions.

Focusing on model direct effects, we found positive, non-zero direct effects of grit-effort (P_1; $\beta = 0.214$, 95% CrI [0.045; 0.380]) and self-discipline (P_3; $\beta = 0.297$, 95% CrI 0.126; 0.459]) on self-reported effort, consistent with model predictions. In addition, self-discipline (P_6; $\beta = .090$, 95% CrI [0.022; 0.162]) and effort (P_7; $\beta = .369$, 95% CrI [0.187; 0.524]) were directly related to grades, as predicted. Credible intervals indicated that zero was a credible value for the effect of grit-interest on effort (P_2; $\beta = 0.051$, 95% CrI [-0.100; 0.199]), and the effects of grit-effort (P_4; $\beta = .044$, 95% CrI [-0.010; 0.100]) and grit-interest (P_5; $\beta =$ 0.018, 95% CrI [-0.024; 0.061]) on grades, consistent with model predictions.

Focusing on model indirect effects, grit-effort was a positive, non-zero predictor of grades through self-reported effort (P_{11}; B = 0.749, 95% CrI [0.140; 1.608]). However, zero was a credible value for indirect effect of grit-interest on grades through effort (P_{12}; B = 0.193, 96% CrI [-0.405; 0.912]). We also found a positive, non-zero indirect effect of self-discipline on grades through effort (P_{13}; B = 0.910, 95% CrI [0.303; 1.762]), a finding which was contrary to predictions[4].

We also found some differences when comparing model posterior distributions of the models using non-informative priors and informative priors. Specifically, the credible intervals for the direct effects of self-discipline on effort (P_3) and grades (P_6), and the indirect effect of self-discipline on grades through effort (P_{13}) included zero as a probable value in the model using non-informative priors, while the intervals for these parameters did not include zero in the model using informative priors. These variations can be attributed to the increased precision of the estimates in the model using informative priors through the narrowing of the credible intervals about the estimates. This illustrates an advantage of adopting a Bayesian approach as the increased accuracy of the estimates using informative priors meant that some important effects would have been missed if conclusions were based on the model adopting uninformative priors. The width of the credible intervals for the two parameters that differed across the models was narrowed by the most substantial margin (Yuan & MacKinnon, 2009).

Discussion

We tested a process model based on Duckworth and Gross' (2014) goal framework in which factors relating to perseverance, grit and self-discipline, predicted high-school students'

[4]We noted the large correlation between the self-discipline and grit-effort constructs (r = .643 in the model with non-informative priors). The large correlation may have been due to overlap and redundancy in the measures of these constructs. Based on the advice of an anonymous reviewer, we re-estimated our models using a revised self-discipline measure that omitted items that overlapped with the grit-effort measure ("I am always prepared", "I often waste my time", "I tend to carry out plans"). Differences in the correlations between the self-discipline and grit-effort constructs across models with the original and revised self-discipline measure were modest (r = .643 vs. r = .604 for the model with non-informative priors) with overlapping CrI. Model fit and patterns of effects in the process model were also near identical. These analyses suggest that the large correlation between these constructs cannot be attributed to particular items, but rather a more fundamental overlap in the measures, and, by inference, the conceptualization of the constructs. Mplus analysis scripts and output for these ancillary analyses are available from https://osf.io/2nzpx/

self-reported effort and attainment in science using Bayesian path-analytic models with non-informative and informative priors. Consistent with our model, we found positive, non-zero direct effects of grit-effort on effort, and effort and self-discipline on science grades. In addition, the effect of grit-effort on grades was mediated by effort consistent with model predictions. Contrary to predictions, we found a positive, non-zero indirect effect of self-discipline on grades mediated by effort. Including informative priors in the analysis had the effect of narrowing of credible intervals of all model parameter estimates.

Current findings have important theoretical and practical implications for the effects of grit and self-discipline on long-term outcomes and the processes involved. The indirect effect of grit-effort on academic attainment is consistent with Duckworth and Gross' (2014) proposal that the process by which gritty individuals pursue long-term goals is through consistent effort on goal directed tasks and behaviours. In particular, we found that high-grit students' effort on out-of-school learning activities set by science teachers contributes to academic attainment in science in the long-term. This finding indicates that gritty students' academic success is, in part, attributable to their tendency to invest effort in out-of-school activities intended to support in-class learning. Although engaging in these activities is not the only determinant of long-term academic performance, it likely plays a key role, consistent with the mediated effect.

That zero was a probable value for the effect of grit-interest on effort provided further support for the differential predictive validity of grit scale dimensions. Although much of the research on grit has tended to adopt the global scale (e.g., Duckworth et al., 2011; Eskreis-Winkler, Duckworth, Shulman, & Beal, 2014; Lucas et al., 2015), studies that have made distinction between the two dimensions have indicated stronger effects for the grit-effort dimension on outcomes (e.g., Bowman et al., 2015; Silvia et al., 2013; Suzuki, Tamesue, Asahi, & Ishikawa, 2015; Von Culin, Tsukayama, & Duckworth, 2014). Our data corroborate findings of a recent meta-analysis, which identified grit-effort dimension as the most consistent predictor of academic outcomes (Credé et al., 2017). Taken together, this emerging pattern

indicates that the grit-effort dimension, reflecting sustained effort on goal-directed tasks to bring about long-term outcomes, is the component of grit that determines academic success. However, further validation across multiple samples in a wider range of contexts is needed to provide converging evidence for the differential prediction of the grit dimensions.

We predicted that self-discipline would be related to self-reported effort and grades, however the effect self-discipline effect would not be mediated by effort. This prediction is based on Duckworth and Gross' (2014) hypothesis that self-discipline is more related to capacity to resolve immediate conflicts rather than long-term goal pursuit. In contrast with expectations, however, we found positive non-zero values for the direct effect of self-discipline on grades, and the indirect effect mediated by effort. A possible reason for the indirect effect is that individuals' capacity to manage immediate situations where response inhibition is required, also contributes to long-term goal pursuit. For example, self-discipline may assist individuals in managing short-term obstacles that might derail effort on behaviours that contribute to long-term goal attainment, like participation in out-of-school learning activities. The direct effect of self-discipline on attainment suggests that capacity for response inhibition, as captured by self-discipline, may be important for performing other actions or behaviours, unmeasured in the current study, that determine academic attainment. For example, self-discipline may lead to greater capacity for resisting temptations or managing distractions that might derail in-class studying activities or attention. These interpretations of the effects of self-discipline are speculative – we cannot corroborate these proposals from current data because we did not measure obstacles to out-of-school learning or in-class effort. Current results, therefore, suggest that both grit-effort and self-discipline are implicated in the process that determines long-term academic outcomes.

It is important to note the similarities and variations in effects across the model estimates using non-informative and informative priors. The majority of model effects were consistent across the two models. However, the narrowing of credible intervals due to specifying

informative priors meant that the intervals about the direct effects of self-discipline on self-reported effort and grades and, as a consequence, the indirect effect of self-discipline on science grades via effort, no longer included zero as a credible value. This demonstrates the importance of including prior values for these effects. However, an important issue for the priors used for these effects was that we used a weakly informative prior for the variance estimate (SD = 0.10) because no variance estimate was available from the source data (Duckworth & Seligman, 2005). We tested whether this variance estimate had a substantial bearing on differences across models. Re-estimating the model with informative priors and varying the prior estimate for variance for these effects (SD range 0.01 to 1.00) revealed that the credible intervals did not encompass zero in any case, and did not, therefore, affect our conclusions. Taken together, these effects provide additional corroboration for the role of self-discipline in predicting grades directly, and via the mediation of self-reported effort.

Current findings have important practical implications for educators and teachers. Given that students' self-reports of greater effort on optional out-of-class science activities was related to science attainment, it seems that encouraging students to try hard on these activities could be important for success in science. Similarly, current findings also indicate that a reason why 'gritty' students, and those with high self-discipline, attain higher grades is partly due to the effort they invest in activities likely to improve their learning. Affecting change in relatively stable, trait-like constructs like grit and self-discipline is difficult. However, implementing means to address some of the specific deficits in motivation and long-term persistence indicated by low grit and self-discipline is a viable option for educational practice. Educators may seek to foster students' motivation to persist on activities outside of school, such as strategies to support self-determined or continuing motivation (e.g., Maehr, 1976; Reeve, Bolt, & Cai, 1999). Such strategies might include setting autonomous goals, providing choice and experiences of success in tasks, deferring responsibility to students, and giving task-related feedback (McLachlan & Hagger, 2010; Pihu, Hein, Koka, & Hagger, 2008). Such

autonomy-supportive strategies are associated with persistence on in-class learning activities as well as academic attainment (Su & Reeve, 2011), and has also been shown to foster motivation toward educational activities outside of school (Hagger, Sultan, Hardcastle, & Chatzisarantis, 2015; Hagger et al., 2016).

Strengths, Limitations, and Recommendations for Future Research

The present study has a number of strengths including the use of a sound theoretical basis, adoption of an appropriate correlational design with three data collection occasions, use of validated theory-based measures, and collection of students' grades to provide an objective measure of academic attainment. The use of a Bayesian analytic approach that incorporated prior research findings was a further strength. It is also important to note some pertinent limitations. First, the correlational design precludes inference of causality in model effects; inferences of directionality are inferred from theory not the data. Second, despite the theoretical and conceptual arguments for self-discipline and grit-effort as separate constructs (Duckworth & Gross, 2014), the high correlation between the measures of the constructs in the present study is indicative of considerable overlap in these constructs at the empirical level, a finding noted elsewhere (Credé et al., 2017; Oriol et al., 2017). While each construct accounted for independent variance in grades and effort in our conceptual model, there was considerable redundancy. The limited evidence for an empirical distinction also presents a problem for theory (Credé et al., 2017), and future research is needed to provide measures capable of reliably distinguishing between these constructs at the empirical level, and test their effects within the our model (see Hagger, 2014). Third, we did not measure each construct of our model at each time point, which meant we could not estimate reciprocal or residualized change in model effects over time. Fourth, we did not control for students' previous academic attainment or measures of ability or intelligence. Although traits related to perseverance predict academic outcomes independent of ability-related constructs (Duckworth & Seligman, 2005), a definitive control for these constructs would provide confirmatory evidence. Fifth, with the

exception of students' grades, measures of constructs in the present study were based exclusively on self-report. We must, therefore, acknowledge the potential for reporting accuracies in measures of psychological traits and effort to introduce error variance in the relations tested in our model. Sixth, as in other research in education, we assumed that students have long-term goals to succeed in science, or, at least, a generalised goal for learning in school. It would be important to support this point by administering measures of students' educational goals. Finally, the present study was conducted on students from a single school, and replications are needed to corroborate these effects in representative samples in multiple educational contexts.

While current data provide an initial test of our process model, a number of avenues for future research are important to further corroborate the proposed effects. For example, model predictions should be estimated in diverse samples of students, from multiple schools, and in different educational contexts. Adoption of a Bayesian analytic approach is also recommended so that current data could be used as priors in keeping with the advocated imperative for using cumulative data to arrive at greater precision in model effects. It would also be important to adopt longitudinal panel designs measuring self-discipline, grit, effort, and grades at multiple time points. Such a design would permit better evaluation of the pattern of effects, including directional and reciprocal effects, and the modelling of change in these constructs over time. In addition, it would be important to include variables relating to ability and actual effort. Ability measures might include general intelligence, executive functioning, cognitive ability, and specific abilities relevant to science such as mathematics and problem solving proficiency, and could be included as covariates in the process model. Including such measures would be expected to explain additional variance in grades, but, consistent with theory on perseverance traits (Duckworth et al., 2007; Zimmerman & Kitsantas, 2014) and the predictions of our process model, we would expect effects of ability and traits on academic attainment to be independent. Finally, in our model, the role of effort as a mediator between grit and self-control

traits and grades was inferred from self-reported effort. However, this would need corroboration using actual measures of effort. Measures of effort might include actual time spent on out-of-school learning activities, perhaps through parental report or time spent on specific internet activities. We envisage 'actual effort' serving as a mediator of the relationship between self-reported effort and grades in a sequential mediation model.

Conclusion

Current findings provide preliminary evidence for the processes by which grit and self-discipline predict long-term educational outcomes. We found that high-school students' self-reported effort on optional out-of-school science activities set by teachers mediated the effects of the perseverance of effort dimension of grit and self-discipline on science grades. Consistent with theory, our model suggests that traits related to perseverance, particularly to the resolution of goal conflicts and suppression of impulse-related dominant responses, are related to sustained effort on activities likely to bring about long-term success in science. Adoption of a Bayesian analytic approach demonstrates the value of including prior knowledge in the testing and development of process-related models in educational contexts.

References

ACARA. (2016). Guide to understanding ICSEA (Index of Community Socioeducational Advantage) values. Retrieved September 1, 2016, from http://www.acara.edu.au/_resources/Guide_to_understanding_icsea_values.pdf

Allom, V., Panetta, G., Mullan, B., & Hagger, M. S. (2016). Self-report and behavioural approaches to the measurement of self-control: Are we assessing the same construct? *Personality and Individual Differences, 90*, 137–142. doi: 10.1016/j.paid.2015.10.051

Ashton, M. C., Lee, K., & Goldberg, L. R. (2007). The IPIP-HEXACO scales: An alternative, public-domain measure of the personality constructs in the HEXACO model. *Personality and Individual Differences, 42*, 1515-1526.

Bowman, N. A., Hill, P. L., Denson, N., & Bronkema, R. (2015). Keep on truckin' or stay the course? Exploring grit dimensions as differential predictors of educational achievement, satisfaction, and intentions. *Social Psychological and Personality Science, 6*, 639-645. doi: 10.1177/1948550615574300

Bowman, S. A., Gortmaker, S. L., Ebbeling, C. B., Pereira, M. A., & Ludwig, D. S. (2004). Effects of Fast-Food Consumption on Energy Intake and Diet Quality Among Children in a National Household Survey. *Pediatrics, 113*, 112-118.

Credé, M., Tynan, M. C., & Harms, P. D. (2017). Much ado about grit: A meta-analytic synthesis of the grit literature. *Journal of Personality and Social Psychology, 113*, 492-511. doi: 10.1037/pspp0000102

Duckworth, A. L., & Gross, J. J. (2014). Self-control and grit: Related but separable determinants of success. *Current Directions in Psychological Science, 23*, 319-325. doi: 10.1177/0963721414541462

Duckworth, A. L., & Kern, M. L. (2011). A meta-analysis of the convergent validity of self-control measures. *Journal of Research in Personality, 45*, 259-268. doi: 10.1016/j.jrp.2011.02.004

Duckworth, A. L., Kirby, T. A., Tsukayama, E., Berstein, H., & Ericsson, K. A. (2011). Deliberate practice spells success: Why grittier competitors triumph at the national spelling bee. *Social Psychological and Personality Science, 2*, 174-181. doi: 10.1177/1948550610385872

Duckworth, A. L., Matthews, M. D., & Kelly, D. R. (2007). Grit: Perseverance and passion for long-term goals. *Journal of Personality and Social Psychology, 92*, 1087-1101. doi: 10.1037/0022-3514.92.6.1087

Duckworth, A. L., & Quinn, P. D. (2009). Development and validation of the Short Grit Scale (Grit–S). *Journal of Personality Assessment, 91*, 166-174. doi: 10.1080/00223890802634290

Duckworth, A. L., & Seligman, M. E. P. (2005). Self-discipline outdoes IQ in predicting academic performance of adolescents. *Psychological Science, 16*, 939-944. doi: 10.1111/j.1467-9280.2005.01641.x

Dumfart, B., & Neubauer, A. C. (2016). Conscientiousness is the most powerful noncognitive predictor of school achievement in adolescents. *Journal of Individual Differences, 37*, 8-15. doi: 10.1027/1614-0001/a000182

Eskreis-Winkler, L., Duckworth, A. L., Shulman, E. P., & Beal, S. (2014). The grit effect: predicting retention in the military, the workplace, school and marriage. *Frontiers in Psychology, 5*. doi: 10.3389/fpsyg.2014.00036

Friese, M., Hofmann, W., & Wiers, R. W. (2011). On taming horses and strengthening riders: Recent developments in research on interventions to improve self-control in health behaviors. *Self and Identity, 10*, 336-351. doi: 10.1080/15298868.2010.536417

Gelman, A., Carlin, J. B., Stern, H. S., Dunson, D. B., Vehtari, A., & Rubin, D. B. (2013). *Bayesian data analysis* (3rd ed.). Boca Raton, FL: CRC Press.

Gelman, A., & Rubin, D. B. (1992). Inference from iterative simulation using multiple sequences. *Psychology, Health & Medicine, 7*, 457-511. doi: 10.1214/ss/1177011136

Gottfredson, M. R., & Hirschi, T. (1990). *A general theory of crime*. Stanford, CA: Stanford University Press.

Hagger, M. S. (2014). Avoiding the 'déjà-variable' phenomenon: Social psychology needs more guides to constructs. *Frontiers in Psychology, 5*, 52. doi: 10.3389/fpsyg.2014.00052

Hagger, M. S., Sultan, S., Hardcastle, S. J., & Chatzisarantis, N. L. D. (2015). Perceived autonomy support and autonomous motivation toward mathematics activities in educational and out-of-school contexts is related to mathematics homework behavior and attainment. *Contemporary Educational Psychology, 41*, 111–123. doi: 10.1016/j.cedpsych.2014.12.002

Hagger, M. S., Sultan, S., Hardcastle, S. J., Reeve, J., Patall, E. A., Fraser, B. J., . . . Chatzisarantis, N. L. D. (2016). Applying the trans-contextual model to mathematics activities in the classroom and homework behaviour and attainment. *Learning and Individual Differences, 45*, 166-175. doi: 10.1016/j.lindif.2015.11.017

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*, 148-161. doi: 10.1037/0022-3514.86.1.148

Lucas, G. M., Gratch, J., Cheng, L., & Marsella, S. (2015). When the going gets tough: Grit predicts costly perseverance. *Journal of Research in Personality, 59*, 15-22. doi: 10.1016/j.jrp.2015.08.004

Maehr, M. L. (1976). Continuing motivation: An analysis of a seldom considered educational outcome. *Review of Educational Research, 46*, 443-462. doi: 10.3102/00346543046003443

McLachlan, S., & Hagger, M. S. (2010). Effects of an autonomy-supportive intervention on tutor behaviors in a higher education context. *Teaching and Teacher Education, 26*, 1205-1211. doi: 10.1016/j.tate.2010.01.006

McNeish, D. (2017). Thanks coefficient alpha, we'll take it from here. *Psychological Methods*. doi: 10.1037/met0000144

Meriac, J. P., Slifka, J. S., & LaBat, L. R. (2015). Work ethic and grit: An examination of empirical redundancy. *Personality and Individual Differences, 86*, 401-405. doi: 10.1016/j.paid.2015.07.009

Muthén, B. O., & Asparouhov, T. (2012). Bayesian structural equation modeling: A more flexible representation of substantive theory. *Psychological Methods, 17*, 313-335. doi: 10.1037/a0026802

Muthén, L. K., & Muthén, B. O. (2012). *MPlus statistical analysis with latent variables: User's guide* (7th ed.). Los Angeles, CA: Muthén & Muthén.

Muthén, L. K., & Muthén, B. O. (2015). *Mplus Statistical Software version 7.31*. Los Angeles, CA: Muthén & Muthén.

NCES. (2012). *Highlights from TIMSS 2011: Mathematics and science achievement of U.S. fourth- and eighth-grade students in an international context*. Washington, DC: National Center for Education Statistics, Institute of Education Sciences (IES).

Oriol, X., Miranda, R., Oyanedel, J. C., & Torres, J. (2017). The role of self-control and grit in domains of school success in students of primary and secondary school. *Frontiers in Psychology, 8*, 1716. doi: 10.3389/fpsyg.2017.01716

Pihu, M., Hein, V., Koka, A., & Hagger, M. S. (2008). How students' perceptions of teacher's autonomy-supportive behaviours affect physical activity behaviour: An application of trans-contextual model. *European Journal of Sport Science, 8*, 193-204. doi: 10.1080/17461390802067679

Poropat, A. E. (2009). A Meta-Analysis of the Five-Factor Model of Personality and Academic Performance. *Psychological Bulletin, 135*, 322-338. doi: 10.1037/a0014996

Quinn, J. M., Pascoe, A. T., Wood, W., & Neal, D. T. (2010). Can't control yourself? Monitor those bad habits. *Personality and Social Psychology Bulletin, 36*, 499-511. doi: 10.1177/0146167209360665

Reeve, J., Bolt, E., & Cai, Y. (1999). Autonomy-supportive teachers: How they teach and motivate students. *Journal of Educational Psychology, 91*, 537-548. doi: 10.1037/0022-0663.91.3.537

Richardson, M., Abraham, C., & Bond, R. (2012). Psychological correlates of university students' academic performance: A systematic review and meta-analysis. *Psychological Bulletin, 138*, 353-387. doi: 10.1037/a0026838

Rohde, T. E., & Thompson, L. A. (2007). Predicting academic achievement with cognitive ability. *Intelligence, 35*, 83-92. doi: 10.1016/j.intell.2006.05.004

Rouder, J. N., Haaf, J. M., & Vandekerckhove, J. (2018). Bayesian inference for psychology, part IV: Parameter estimation and Bayes factors. *Psychonomic Bulletin & Review, 25*, 102-113. doi: 10.3758/s13423-017-1420-7

Silvia, P. J., Eddington, K. M., Beaty, R. E., Nusbaum, E. C., & Kwapil, T. R. (2013). Gritty people try harder: Grit and effort-related cardiac autonomic activity during an active coping challenge. *International Journal of Psychophysiology, 88*, 200-205. doi: 10.1016/j.ijpsycho.2013.04.007

Su, Y. L., & Reeve, J. (2011). A meta-analysis of the effectiveness of intervention programs designed to support autonomy. *Educational Psychology Review, 23*, 159-188. doi: 10.1007/s10648-010-9142-7

Suzuki, Y., Tamesue, D., Asahi, K., & Ishikawa, Y. (2015). Grit and work engagement: A cross-sectional study. *PLoS ONE, 10*, 11. doi: 10.1371/journal.pone.0137501

Tangney, J. P., Baumeister, R. F., & Boone, A. L. (2004). High self-control predicts good adjustment, less pathology, better grades, and interpersonal success. *Journal of Personality, 72*, 271-324. doi: 10.1111/j.0022-3506.2004.00263.x

Thomson, S., Wernert, N., O'Grady, E., & Rodrigues, S. (2016). *TIMSS 2015: A first look at Australia's results*. Camberwell, Victoria: Australian Council for Educational Research.

Trautwein, U., Ludtke, O., Kastens, C., & Koller, O. (2006). Effort on homework in grades 5-9: Development, motivational antecedents, and the association with effort on classwork. *Child Development, 77*, 1094-1111. doi: 10.1111/j.1467-8624.2006.00921.x

Trope, Y., & Fishbach, A. (2000). Counteractive self-control in overcoming temptation. *Journal of Personality and Social Psychology, 79*, 493-506.

van de Schoot, R., Kaplan, D., Denissen, J., Asendorpf, J. B., Neyer, F. J., & van Aken, M. A. G. (2014). A gentle introduction to Bayesian analysis: Applications to developmental research. *Child Development, 85*, 842-860. doi: 10.1111/cdev.12169

Von Culin, K. R., Tsukayama, E., & Duckworth, A. L. (2014). Unpacking grit: Motivational correlates of perseverance and passion for long-term goals. *The Journal of Positive Psychology, 9*, 306-312. doi: 10.1080/17439760.2014.898320

Wolters, C. A., & Hussain, M. (2015). Investigating grit and its relations with college students' self-regulated learning and academic achievement. *Metacognition and Learning, 10*, 293-311. doi: 10.1007/s11409-014-9128-9

Yuan, Y., & MacKinnon, D. P. (2009). Bayesian mediation analysis. *Psychological Methods, 14*, 301-322. doi: 10.1037/a0016972

Zimmerman, B. J., & Kitsantas, A. (2005). Homework practices and academic achievement: The mediating role of self-efficacy and perceived responsibility beliefs. *Contemporary Educational Psychology, 30*, 397-417. doi: 10.1016/j.cedpsych.2005.05.003

Zimmerman, B. J., & Kitsantas, A. (2014). Comparing students' self-discipline and self-regulation measures and their prediction of academic achievement. *Contemporary Educational Psychology, 39,* 145-155. doi: 10.1016/j.cedpsych.2014.03.004

Zyphur, M. J., & Oswald, F. L. (2015). Bayesian estimation and inference: A user's guide. *Journal of Management, 41*, 390-420. doi: 10.1177/0149206313501200

Table 1
Summary of Predicted Direct and Indirect Effects in the Process Model of Grit Subscales, Self-Discipline, Effort, and Academic Attainment and Proposed Informative Prior Estimates for Bayesian Path Analysis

Effect		Prediction	Informative priors		
			r	SD	Source
Direct effects					
P_1	Grit–Effort→Effort†	+ Effect	.370	0.10	Meriac et al. (2015)
P_2	Grit–Interest→Effort†	No effect	.150	0.10	Meriac et al. (2015)
P_3	Self-discipline→Effort†	+ Effect	.670	0.10	Duckworth & Seligman (2005)
P_4	Grit–Effort→Science Grades	No effect	.290	0.08	Credé et al. (2017)
P_5	Grit–Interest→Science Grades	No effect	.130	0.06	Credé et al. (2017)
P_6	Self-discipline→Science Grades†	+ Effect	.630	0.10	Duckworth & Seligman (2005)
P_7	Effort→Science Grades	+ Effect	.320	1.44	Richardson et al. (2012)
Correlations					
P_8	Grit–Effort↔Grit–Interest	+ Effect	.600	0.21	Credé et al. (2017)
P_9	Grit–Effort↔SD	+ Effect	.590	0.05	Credé et al. (2017)
P_{10}	Grit–Interest↔SD	+ Effect	.590	0.05	Credé et al. (2017)
Indirect effects					
P_{11}	Grit–Effort→Effort→Science Grades	+ Effect	–	–	–
P_{12}	Grit–Interest→Effort→Science Grades	No effect	–	–	–
P_{13}	Self-discipline→Effort→Science Grades	No effect	–	–	–

Note. *r* = Informative prior estimate (correlation coefficient); SD = Standard deviation of prior; Grit–Effort = Grit – Perseverance of Effort; Grit–Interest = Grit – Consistency of Interest; + Effect = Parameter expected to be positive and non-zero; No effect = Parameter expected to be trivial in size or have zero as a probable value; †Variance estimates for these parameters not based on empirical evidence.

Table 2
Descriptive Statistics and Intercorrelations for Grit Subscales, Self-Discipline, Effort, Science Grades, and Demographic Variables

Variable	ω	*M*	SD	1	2	3	4	5	6	7
1. Grit–Effort	.72	2.882	0.642	1.000						
2. Grit–Interest	.50	2.468	0.578	.422***	1.000					
3. Self-discipline	.81	3.364	0.737	.640***	.379***	1.000				
4. Effort	.96	4.396	1.585	.495***	.200*	.424***	1.000			
5. Science grades[a]	.89	31.618	6.805	.432***	.251**	.379***	.431***	1.000		
6. Age	–	12.800	0.711	.161	.123	.056	.166	.128	1.000	
7. Gender[b]	–	–	–	.014	-.039	.059	-.125	.063	.026	1.000

Note. ω = Omega reliability coefficient (McNeish, 2017); *M* = Mean; SD = Standard deviation; Grit–Effort = Grit – Perseverance of Effort; Grit–Interest = Grit – Consistency of Interest. [a]Spearman-Brown correlation between two science grade scores; [b]Gender variable coded as 1 = female, 2 = male.
***$p < .001$ **$p < .01$ *$p < .05$.

Table 3

Parameter Estimates with 95% Credible Intervals for Hypothesised Effects from the Bayesian Path Analyses of the Grit Subscales, Self-Discipline, Effort, and Science Attainment Process Model

Effect		Model with Non-Informative Prior			Model with Informative Prior			%diff
		Estimate	95% CrI		Estimate	95% CrI		
			LL	UL		LL	UL	
Direct effects[a]								
P_1	Grit–Effort→Effort	0.366***	0.133	0.576	0.214**	0.045	0.380	-10.80
P_2	Grit–Interest→Effort	-0.053	-0.250	0.146	0.051	-0.100	0.199	-9.70
P_3	Self-discipline→Effort	0.210	-0.014	0.423	0.297***	0.126	0.459	-10.40
P_4	Grit–Effort→Science Grades	0.184	-0.057	0.415	0.044	-0.010	0.100	-36.20
P_5	Grit–Interest→Science Grades	0.075	-0.113	0.258	0.018	-0.024	0.061	-28.60
P_6	Self-discipline→Science Grades	0.103	-0.120	0.325	0.090**	0.022	0.162	-30.50
P_7	Effort→Science Grades	0.283**	0.065	0.481	0.369***	0.187	0.524	-7.90
Correlations[a]								
P_8	Grit–Effort↔Grit–Interest	0.412***	0.239	0.562	0.449***	0.278	0.594	-0.70
P_9	Grit–Effort↔SD	0.643***	0.514	0.744	0.669***	0.545	0.763	-1.20
P_{10}	Grit–Interest↔SD	0.380***	0.203	0.534	0.427***	0.254	0.576	-0.90
Indirect effects[b]								
P_{11}	Grit–Effort→Effort→Science Grades	1.036**	0.168	2.392	0.749**	0.140	1.608	-75.60
P_{12}	Grit–Interest→Effort→Science Grades	-0.146	-0.980	0.537	0.193	-0.405	0.912	-20.00
P_{13}	Self-discipline→Effort→Science Grades	0.499	-0.043	1.451	0.910**	0.303	1.762	-3.50

Note. H = Hypothesis; 95% CrI = 95% credible interval of parameter estimate; LL = Lower limit of 95% CrI; UL = Upper limit of 95% CrI; %diff = Percent difference in 95% CrI of parameter estimates using informative priors compared to analysis using non-informative priors

(negative numbers indicate a narrowing of credible intervals when using informative priors); Grit–Effort = Grit – Perseverance of Effort; Grit–Interest = Grit – Consistency of Interest. [a]Values are standardised estimates; [b]Values are unstandardised estimates.
$^{*}p < .05$ $^{**}p < .01$ $^{***}p < .001$

Figure 1a. The proposed grit, self-discipline, effort, and academic attainment process model. Solid lines reflect free parameters (P) predicted to have positive and non-zero values and broken lines represent free parameters expected to have zero as a credible value. Indirect effects expected to have non-zero values not illustrated in the diagram: Indirect effect of grit-perseverance of effort on science grades via effort (P_{11}). Indirect effects expected to be trivial or zero not illustrated in the diagram: Indirect effect of grit-consistency of interest on science grades via effort (P_{12}) and indirect effect of self-discipline on science grades via effort (P_{13}).

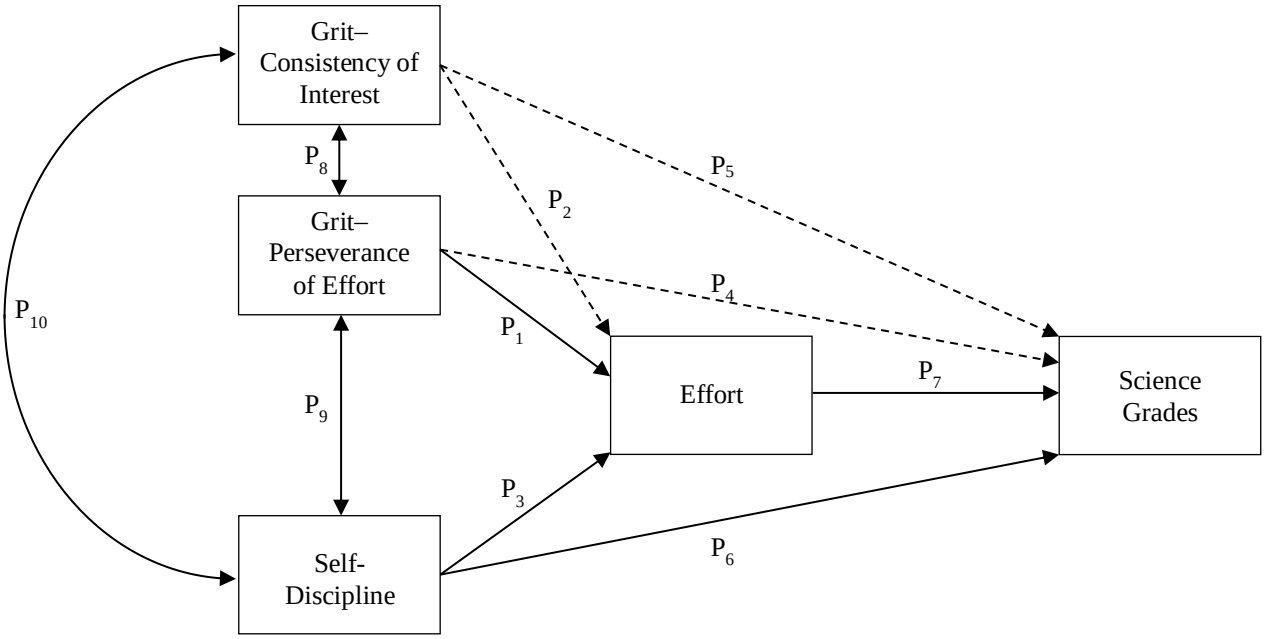


Figure 1b. Process model including parameter estimates and 95% credible intervals from Bayesian path analysis with non-informative prior values. Parameter estimates for indirect effects not illustrated in the diagram: Indirect effect of grit-perseverance of effort on science grades via effort, B = 1.036 [0.168, 2.392]; Indirect effect of grit-consistency of interest on science grades via effort, B = -0.146 [-0.980, 0.537]; Indirect effect of self-discipline on science grades via effort, B = 0.499 [-0.043, 1.451].

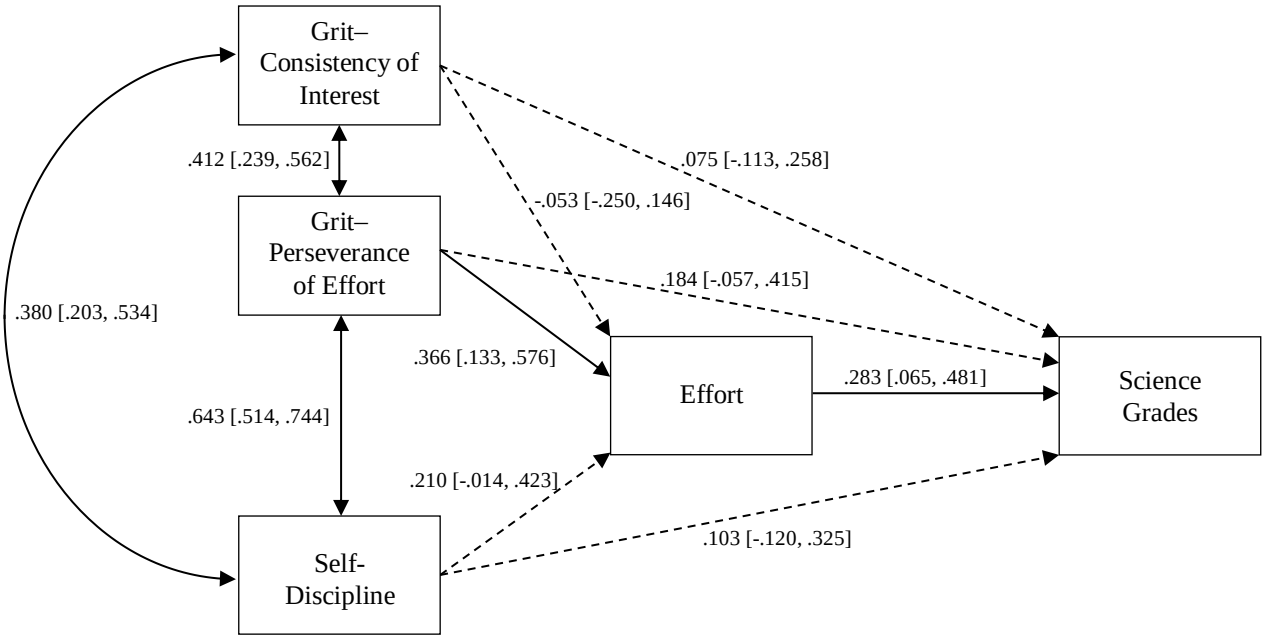
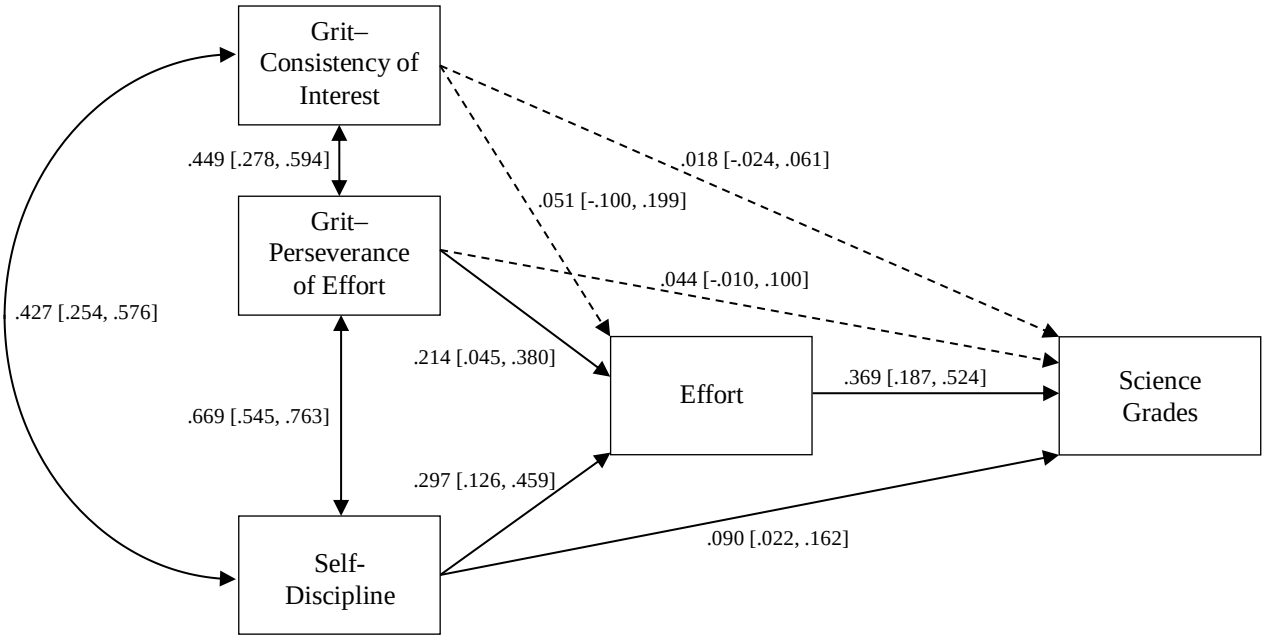


Figure 1c. Process model including parameter estimates and 95% credible intervals from Bayesian path analysis with informative prior values. Parameter estimates for indirect effects not illustrated in the diagram: Indirect effect of grit-perseverance of effort on science grades via effort, B = 0.749 [0.140, 1.608]; Indirect effect of grit-consistency of interest on science grades via effort, B = 0.193 [-0.405, 0.912]; Indirect effect of self-discipline on science grades via effort, B = 0.910 [0.303, 1.762].



Supporting Information: Appendix B

Appendix A. Details of Scales Used to Measure Constructs in the Process Model

Measure	Subscale (if applicable)	Items	Scale (if applicable)
Short Grit Scale (Grit-S, Duckworth & Quinn, 2009)	Consistency of Interest	I often set a goal but later choose to pursue a different one.(R) New ideas and projects sometimes distract me from previous ones.(R) I have been obsessed with a certain idea or project for a short time but later lost interest.(R) I have difficulty maintaining my focus on projects that take more than a few months to complete.(R)	1 = Not at all like me, 4 = Very much like me.
	Perseverance of Effort	I finish whatever I begin. Setbacks don't discourage me. I am a hard worker. I am diligent.	1 = Not at all like me, 4 = Very much like me.
Self-discipline (Ashton et al., 2007)		I have difficulty starting tasks (R). I get my chores done right away. I find it difficult to get down to work (R). I am always prepared. I often waste my time (R). I start tasks right away. I tend to postpone decisions (R). I like to get to work at once. I need a push to get started (R). I tend to carry out my plans.	1 = Not at all, 5 = Very much
Effort		During the last 5 weeks, how hard did you try to... [common stem] …do your science activities at home? ….maintain your willpower to do your science activities at home? ….be self-disciplined and do your science activities at home? …spend time in planning to do your science activities at home? … expend a lot of mental energy in doing your science activities at home?	1 = Did not try at all, 7 = Tried extremely hard
Science grades		Students' final semester science grade calculated as an average of grades on in-school science assignments over the semester.	–

Note. (R) = Item is reverse scored.