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Abstract

The Program for International Student Assessment (PISA) aims to provide comparative data on 15-year-olds' academic performance and well-being. The purpose of the current study is to explore and compare the variables that predict the reading literacy and life satisfaction of U.S. and South Korean students. The random forest algorithm, which is a machine learning approach, was applied to PISA 2018 data (4,677 U.S. students and 6,650 South Korean students) to explore and select the key variables among 305 variables that predict reading literacy and life satisfaction. In each random forest analysis, one for the U.S. and another for South Korea, 23 variables were derived as key variables in students' reading literacy. In addition, 23 variables in the U.S. and 26 variables in South Korea were derived as important variables for students' life satisfaction. The multilevel analysis revealed that various student-, teacher- or school-related key variables derived from the random forest were statistically related to either U.S. and/or South Korean students' reading literacy and/or life satisfaction. The current study proposes to use a machine learning approach to examine international large-scale data for an international comparison. The implications of the current study and suggestions for future research are discussed.

Keywords: reading literacy, life satisfaction, PISA 2018, international comparison, United States, South Korea

Un Estudio de Comparación Internacional que Explora las Variables Influyentes que Afectan la Competencia Lectora y la Satisfacción con la Vida de los Estudiantes

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Resumen

El Programa para la Evaluación Internacional de Alumnos (PISA) tiene como objetivo proporcionar datos comparativos sobre el rendimiento académico y el bienestar de los jóvenes de 15 años. El propósito del presente estudio es explorar y comparar las variables que predicen la competencia lectora y la satisfacción vital de estudiantes estadounidenses y coreanos. El algoritmo de bosque aleatorio, que es un enfoque de aprendizaje automático, se aplicó a los datos de PISA 2018 (4.677 estudiantes estadounidenses y 6.650 estudiantes coreanos) para explorar y seleccionar las variables clave entre 305 variables que predicen la competencia lectora y la satisfacción vital. En cada análisis de bosque aleatorio, uno para Estados Unidos y otro para Corea, se derivaron 23 variables como variables clave en la competencia lectora de los estudiantes. Además, se derivaron 23 variables en EE.UU. y 26 variables en Corea como variables importantes para la satisfacción vital de los estudiantes. El análisis multinivel reveló que varias variables clave relacionadas con los estudiantes, los profesores o la escuela, derivadas del bosque aleatorio, estaban estadísticamente relacionadas con la competencia lectora y/o la satisfacción vital de los estudiantes estadounidenses y/o coreanos. El presente estudio propone utilizar un enfoque de aprendizaje automático para examinar los datos internacionales a gran escala para una comparación internacional. Se discuten las implicaciones del presente estudio y las sugerencias para futuras investigaciones.

Palabras clave: competencia lectora, satisfacción con la vida, PISA 2018, comparación internacional, Estados Unidos, Corea

The current study aims to compare U.S. and Korean students by focusing on key variables that predict reading literacy and life satisfaction, examining similarities and differences between the two countries. Considering U.S. and Korea as representative Western and Eastern countries, respectively, previous studies (e.g., Shin et al., 2013; Won & Han, 2010) have compared various educational factors (e.g., academic achievement, curricula) between the two countries to explain similarities and differences in academic performance (Park & Huebner, 2005; Shin et al., 2009). The current study was designed to explore and compare the key variables that predict life satisfaction and reading literacy in the two countries.

Many studies have investigated the impact of various predictors on students' reading literacy and life satisfaction in the U.S. and Korea. For reading literacy, previous studies have reported that various student- ('gender', 'ESCS', 'metacognitive strategies', 'competence to assess credibility' (Gamazo & Martínez-Abad, 2020; Lim & Jung, 2019; Reilly, 2012; Shin et al., 2013), 'teacher- and/or school-related variables ('a number of total enrollments', 'students' behavior that hindered learning', and 'teacher-to-student ratio' (Kang & Yum, 2013; Lee & Ku, 2019) are associated with U.S. and Korean students' reading literacy. Interestingly, 'ICT availability at home', 'ICT usage at school for general purposes', 'ICT availability at school', and 'ICT usage for entertainment purposes' were associated with Korean students only (Kim, 2012; Lee & Ku, 2019), whereas 'a number of total enrollments' was associated with U.S. students only (Barrett & Toma, 2013).

For life satisfaction, previous literature using Program for International Student Assessment (PISA) data reported various student- ('gender', 'ESCS', 'home possessions', 'meaning in life', 'resilience', 'general fear of failure', 'parental emotional support' (Cho, 2019; Guess & McCane-Bowling, 2016; Tang, 2019), teacher- and/or school-related variables ('school type', and 'school size' (Cho, 2019; Park & Chung, 2020) as important factors in predicting U.S. and/or Korean students' life satisfaction. Interestingly, 'attitude toward school learning activities' and 'perception of cooperation at school' were associated with Korean students only, whereas 'sense of belonging to school', 'teachers' support' and 'perceived feedback' were associated with U.S. students only (Rudolf, 2020).

The Current Study

The current study integrates the advantages of both machine learning and statistical modeling to explore and test predictors of academic achievement and life satisfaction. Previous studies have typically incorporated a subset of selected predictors from hundreds of survey variables in the PISA based on review of the literature or theoretical background and examined the impact of the predictors on academic and/or noncognitive achievement using traditional statistical modeling (Dong & Hu, 2019). Machine learning approaches can explore influential new variables that have been overlooked in the literature. Recently, in educational fields, researchers have attempted to apply machine learning techniques to large-scale datasets to explore new variables instead of selecting a set of variables based on the theoretical background (Dong & Hu, 2019). The current study thoroughly reviews previous studies and summarizes the variables that are known to be significant factors in reading literacy and life satisfaction. Then, the study employs a machine learning method, random forest (Breiman, 2001), to explore key variables that might have been overlooked in the previous literature among the hundreds of survey variables in the PISA.

The present study further conducted multilevel modeling (Raudenbush & Bryk, 2002), which is a statistical method of accounting for clustered data, in which students are nested within schools to statistically test the impact of key variables derived from random forest analysis on reading literacy and life satisfaction. It compared the impact of the key predictors of reading literacy and life satisfaction between students in the U.S. and South Korea using the results from PISA 2018.

The following research questions guided the current study: What are the statistically significant key variables that predict students' reading literacy and/or life satisfaction in the U.S. and South Korea? How are the variables similar and different across the two countries?

Literature Review

According to OECD (2019c), reading literacy is defined “as understanding, using, evaluating, reflecting on and engaging with texts in order to achieve one’s goals, to develop one’s knowledge and potential and to participate in society” (p. 15). Life satisfaction is referred to as ‘students’ overall evaluation

of their lives' (OECD, 2019c, p. 41). Life satisfaction is a useful summary indicator of well-being widely used by national statistical offices (OECD, 2019c). Several student- and school-related variables have been reported as significant factors explaining the reading literacy and life satisfaction of students in the U.S. and Korea, as well as students from other countries. The current section reviewed the literature using PISA data and other non-PISA data and summarized the main factors associated with reading literacy and life satisfaction of students in the U.S. and Korea, as well as students from other countries.

The Variables Predicting Reading Literacy

Student-related variables. Many studies have explored the impact of student-related variables, such as students' background variables, cognitive and affective variables, ICT-related variables and social environmental variables, on reading literacy, and these factors have been reported to be predictors of U.S. and Korean students' reading literacy. Students' background variables, such as 'gender' and 'economic, social and cultural status (ESCS)', are associated with reading literacy in both the U.S. and Korea. For example, girls achieve higher reading literacy than boys (Reilly, 2012), and the higher adolescents' 'ESCS' is, the higher their reading literacy scores on tests in both countries (Shin et al., 2013).

Students' cognitive and affective variables, such as 'metacognitive strategies', 'competence to assess credibility', and 'mastery goals', are positively associated with U.S. and Korean students' reading literacy (Gamazo & Martínez-Abad, 2020; Kaplan & Maehr, 1999; Lim & Jung, 2019). U.S. students' competence to assess credibility is positively associated with reading literacy (Gamazo & Martínez-Abad, 2020), and U.S. students who are oriented toward 'mastery goals' tend to perform better academically than students with performance goals (Kaplan & Maehr, 1999). On the other hand, students' metacognition of reading (summarizing, understanding and memory strategies) was positively associated with reading literacy in 15 countries, including Korea, using PISA datasets (Lim & Jung, 2019¹).

The impact of students' ICT-related variables on students' academic achievement is somewhat inconsistent across previous studies. For example, 'ICT availability at home' and 'ICT usage at school for general purposes' are

negatively related to Korean reading literacy. Moreover, ‘ICT availability at school’ and ‘ICT usage for entertainment purposes’ are negatively related to Korean reading literacy (Kim, 2012). However, few studies of U.S. students using PISA datasets predict reading literacy using ICT-related variables. Moreover, students’ social environmental variables, such as ‘a sense of belonging to school’, are not statistically significant for Korean students’ reading literacy (Lee & Ku, 2019). However, the relationship between the students’ social environmental variables and reading literacy has been relatively less studied than the other student-related variables.

Based on findings for students in other countries (e.g., Australia, China, Finland, France, Mexico, New Zealand, Singapore, Turkey) using PISA data, ‘students’ grade repetition’ (Dong & Hu, 2019), ‘fear of failure’ (Koyuncu & Firat, 2020), ‘fixed mindset’ (Claro et al., 2016), and ‘ICT availability at school’ (Xiao & Hu, 2019) were found to negatively influence reading literacy. Moreover, ‘perceived emotional support from parents’ and ‘schools’ classroom disciplinary climate’ are significantly positively associated with students’ academic achievement (Ertem, 2020). However, ‘cooperation at school’ is negatively related to students’ reading literacy (Ertem, 2020).

Teacher- and school-related variables. In addition to student-related variables, previous studies have reported that teacher- and school-related variables are also important factors in predicting adolescents’ reading literacy. A high number of total enrollments is statistically positively associated with the U.S. students’ academic achievement (Barrett & Toma, 2013). Moreover, Korean students’ behavior that hinders learning and affects school climate is statistically negatively associated with students’ reading literacy (Lee & Ku, 2019). The ‘teacher-to-student ratio’ is significantly positively associated with Korean reading literacy (Kang & Yum, 2013). However, ‘school size’, ‘school type’, ‘number of available computers per student’, and ‘teacher behavior that hindered learning’ are not significantly associated with Korean students’ reading literacy (Kang & Yum, 2013; Lee & Ku, 2019).

Findings from previous studies using PISA data that focused on students in countries other than the U.S. and Korea, including schools with a higher proportion of lower-level socioeconomic students and schools with a shortage of educational materials, tended to show relatively low academic achievement (Ertem, 2020; Perry & McConney, 2010). ‘School size’ is positively related

to students' reading literacy; however, the 'teacher-to-student ratio' is negatively related to students' reading literacy (Topçu et al., 2015). However, these results somewhat differ from findings in studies that used Korean students' datasets (Kang & Yum, 2013; Lee & Ku, 2019). In addition, teachers' qualifications (for example, a master's degree in the subject or pedagogy and a teacher certificate) are positively associated with students' academic performance (Fuchs & Wößmann, 2007).

The Predicting Variables on Life Satisfaction

Student-related variables. A few of the previous studies using PISA data have reported that students' background, cognitive and affective, ICT-related, and/or social environmental variables are associated with their life satisfaction in the U.S. and Korea. Regarding students' background variables, previous studies reported that girls are less satisfied with life than boys and that 'ESCS' was strongly associated with students' life satisfaction in both the U.S. and Korea (Tang, 2019). Rudolf (2020) noted that 'home possessions', such as a desk and a quiet place to study, are positively related to life satisfaction in the U.S., while 'home possessions' are not statistically significant in Korea.

Students' cognitive and affective variables, such as the effects of students' perception of 'meaning in life', 'resilience', 'mastery goal orientation', and 'general fear of failure', on life satisfaction have been noted. The U.S. and Korean students' perception of 'meaning in life' and 'resilience' are strongly positively associated with life satisfaction (Rudolf, 2020). However, the U.S. and Korean students with a higher 'fear of failure' tend to show lower overall life satisfaction (Rudolf, 2020). Moreover, U.S. students with 'mastery goals' tend to show higher overall life satisfaction than those with performance goals (Kaplan & Maehr, 1999).

Recently, a few studies have investigated the relationship between students' ICT-related variables and life satisfaction. Cho (2019) studied 40 countries, including the U.S. and Korea, finding that educational resources at home and ICT-related variables as well as the availability of digital devices in schools are associated with students' life satisfaction based on the PISA 2015. However, few studies have investigated the association between ICT-related variables and life satisfaction in the U.S.

In addition, social environmental variables have been reported to be predictors of students' life satisfaction. The impact of 'parental emotional support', 'attitude toward school learning activities', and 'perception of cooperation at school' is positively related to Korean life satisfaction (Rudolf, 2020). However, students' perception of competitiveness at school is negatively related to Korean life satisfaction (Rudolf, 2020). Moreover, 'parental emotional support', 'sense of belonging to school', 'teachers' support' and 'perceived feedback' are positively related to U.S. students' life satisfaction (Guess & McCane-Bowling, 2016; Rudolf, 2020). Additionally, higher-frequency internet use is weakly associated with lower life satisfaction in Bulgaria and Chile (Kardefelt-Winther et al., 2020).

Teacher- and school-related variables. Most studies investigating variables' impact on overall life satisfaction include student-related variables, while a few studies have focused on teacher- and school-related variables' impact on life satisfaction. Park and Chung (2020) revealed that Korean students attending public schools are more likely to have higher life satisfaction than those attending private schools.

In addition, Cho (2019) revealed that students from 40 countries, including the U.S. and Korea, who attend schools with a high proportion of socioeconomically disadvantaged families, tend to be more satisfied with life. Moreover, Cho (2019) found that students who attend schools in large cities tend to be less satisfied with their lives than those who attend schools in villages, hamlets, rural areas, or small towns or cities.

Moreover, students who attend public schools show higher life satisfaction than students who attend private schools. Gilman (2001) found that 'extracurricular activities', such as band, orchestra or choir, volunteering, book clubs, art clubs or art activities, and sporting teams at school, are positively correlated with students' life satisfaction in southeastern states. Based on findings in previous literature using PISA data, various student-, teacher- and school-related variables were found to be important factors in predicting students' reading literacy and life satisfaction.

Methods

Data and Participants

The current study used U.S. and South Korean samples from the PISA 2018 datasets. The student (15-year-olds) participants included 4,677 U.S. students from 164 schools and 6,650 Korean students from 188 schools who participated in the PISA 2018. In the U.S., 2,369 (50.7%) students were boys, and 2,308 (49.3%) students were girls; in Korea, 3,459 (52%) students were boys, and 3,191 (48%) students were girls.

Variables

Students' reading literacy and life satisfaction were used as the dependent variables in the current study. The reading literacy scores were reported as 10 plausible values with a mean of approximately 500 and a standard deviation of approximately 100 across countries (OECD, 2019b). The life satisfaction scale ranges from 0 to 10 (OECD, 2019c). In addition, a total of 305 (132 student-, 78 teacher- and 95 school-related) variables were used as independent variables. Further details can be found in Appendix.

Analyses

Random forest. The current study employed the random forest method, which is a machine learning technique, to explore key variables among 305 independent variables involved in predicting the reading literacy or life satisfaction of students in the U.S. and Korea. Random forest can be used to explore influential new variables that have been overlooked in the literature. In the supervised machine learning procedure, 70% of the available data were allocated for the training dataset, and the remaining 30% were reserved for the test dataset.

The key variables were derived based on the following two variable factors for each variable: 1) *MSE* (mean squared error) and 2) *purity* (Dewi & Chen, 2019). The random forest analyses were performed using the R package "randomForest" (Ver. 4.6-14) in R (Breiman et al., 2018). Missing data were addressed through multiple imputations with 10 replications using the "mice" package (Ver. 3.12.0) in R (van Buuren & Groothuis-Oudshoorn, 2011).

The level-one equation for unconditional multilevel modeling is as follows:

$$Y_{ij} = \beta_{0j} + e_{ij} \tag{1}$$

The level-two equation for unconditional multilevel modeling is as follows:

$$\beta_{0j} = \gamma_{00} + u_{0j} \tag{2}$$

where Y_{ij} indicates the outcome for student i who attended school j . β_{0j} represents the average outcome for school j . e_{ij} is the level-one residual, $e_{ij} \sim N(0, \sigma^2)$. γ_{00} represents the overall average outcome, u_{0j} is the level-two residual, and $u_{0j} \sim N(0, \tau_{00})$. The level-one equation for conditional multilevel modeling is as follows:

$$Y_{ij} = \beta_{0j} + \sum_{p=1}^P \beta_{pj} X_{pij} + e_{ij}, \text{ for } p = 1 \dots P \tag{3}$$

The level-two equation for conditional multilevel modeling is as follows:

$$\begin{cases} \beta_{0j} = \gamma_{00} + \sum_{q=1}^Q \gamma_{0q} Z_{qj} + u_{0j} \\ \beta_{1j} = \gamma_{10} \\ \vdots \\ \beta_{pj} = \gamma_{p0} \end{cases}, \text{ for } q = 1 \dots Q \tag{4}$$

where X_{pij} are the student-related predictors for student i from school j and Z_{qj} are the teacher- and school-related predictors for school j . Note that the effects of level-one predictors were fixed across schools. In the PISA 2018, 10 plausible value estimates were generated to present students’ reading literacy (OECD, 2019b) and handled by *Mplus* 8.4 software (Muthén & Muthén, 1998-2019). The current study also used the country weight factor, SENWT (senate weight), to ensure that each country contributed equally to the multilevel analysis (OECD, 2019a; Shin et al, 2009).

Results

Random Forest Results

Table 1 describes the key features if the predictors were derived 10 times based on either *MSE* or *purity* among 30 key features derived by running a random model using 10 imputed datasets in the U.S. or Korea (see Table 1). In each random forest analysis, one for the U.S. and another for Korea, 23 variables were derived as key variables in students’ reading literacy. In addition, 23 variables in the U.S. and 26 variables in Korea were derived as important variables for students’ life satisfaction.

Table 1
Key variables selected from the random forest

Variables	Reading literacy		Life satisfaction	
	U.S.	Korea	U.S.	Korea ^a
Student-related				
<i>Students' background variables</i>				
Student gender				□
Index of economic, social and cultural status	●	●	●	●
ISEI of father	◆	◆	□	
Family wealth		◇	■	■
Grade repetition	◇			
<i>Students' cognitive and affective variables</i>				
Meta-cognition: Understanding and remembering	◆	◆		
Meta-cognition: Summarizing	◆	◆		
Meta-cognition: Assess credibility	◆	◆		
Joy/Like reading	◆	◆		□
Students' expectations of completing ISCED level 5A or 6	◆	◆		
Student's expected occupational status	◆	◆	□	
Self-concept of reading: Perception of competence	◆	◆		
Self-concept of reading: Perception of difficulty	◆	◆		
Perception of difficulty of the PISA test	◆	◆		
The degree of efforts that students put into this test		◇		
The degree of efforts that students have invested	◆	◆		
Feeling: Afraid				□
Feeling: Scared				□
Feeling: Lively			■	■
Feeling: Sad			■	■
Feeling: Proud			■	■
Feeling: Miserable			■	■
Subjective well-being: Positive affect			■	■
Mastery goal orientation			■	■
General fear of failure	◇		■	■
Eudaemonia: Meaning in life			■	■
Resilience			■	■
Fixed mindset	◇			
<i>ICT-related variables</i>				
Interest in ICT	●	●	●	●

ICT resources				□
Perceived ICT competence				□
Perceived autonomy related to ICT use			■	■
Use of ICT outside of school for schoolwork		◇		
ICT available at home	●	●	●	●
ICT available at school	●	●	●	●
ICT usage at school	◇			
ICT use outside of school for leisure	◆	◆		□
<i>Students' social environmental variables</i>				
Parents' emotional support			■	■
Teacher-directed instruction			□	
Teacher support in test language lessons			□	
Perceived feedback				□
Disciplinary climate in test language lessons	◇		□	
The length of text that students had to read for the test language lessons	◇			
Subjective well-being: Sense of belonging to school			■	■
Perception of cooperation at school				□
Attitude toward school: learning activities				□
Teacher- and School-related				
<i>Teacher related variables</i>				
Teacher-related variables such as the length of text that students had to read for the lessons		◇		
<i>School related variables</i>				
Student behavior hindering learning affecting school climate		◇		
Number of available computers per student at modal grade		◇		
The percentage of students from socioeconomically disadvantaged homes	◆	◆		

Note: ● = a variable selected from both U.S. and Korea in reading literacy and life satisfaction; ◆ = a variable selected from both U.S. and Korea in reading literacy; ■ = a variable selected from both U.S. and Korea in life satisfaction; ◇ = a variable selected only from U.S. or Korea in reading literacy; □ = a variable selected only from U.S. or Korea in life satisfaction

Multilevel Modeling Analysis Results

In selecting the variables to be tested using multilevel modeling, some variables derived from random forest analyses were excluded before running multilevel modeling due to their high correlation with other variables (e.g., four variables for reading literacy and five variables for life satisfaction).

Descriptive statistics. Table 2 shows the descriptive statistics of variables used in the multilevel modeling analysis between the U.S. and Korea.

Table 2
Descriptive statistics on predictors

Variables	Answer or rating	U.S.				Korea			
		<i>M</i>	<i>S.D</i>	<i>Mi n</i>	<i>Ma x</i>	<i>M</i>	<i>S.D</i>	<i>Mi n</i>	<i>Ma x</i>
Student-related									
<i>Students' background variables</i>									
Student gender	"0 = male" "1 = female"	0.49	0.50	0.00	1.00	0.48	0.50	0.00	1.00
Index of economic, social and cultural status		0.08	1.01	-4.00	3.00	0.09	0.77	-	4.00
ISEI of father	<i>d.v.</i>	42.9 6	22.0 9	11.5 6	88.7 0	45.0 9	19.5 6	11.0 1	88.7 0
Family wealth		0.42	1.04	-7.00	4.00	-	0.56	-	4.00
Grade repetition	"0 = did not repeat a grade" "1 = repeated a grade"	0.10	0.30	0.00	1.00	0.05	0.21	0.00	1.00
<i>Students' cognitive and affective variables</i>									
Meta-cognition: Understanding and remembering		-0.07	1.00	-1.64	1.50	-	1.08	-	1.50
Meta-cognition: Summarizing	<i>d.v.</i>	-0.05	1.00	-1.72	1.36	-	1.10	-	1.36
Meta-cognition: Assess credibility		-0.01	0.99	-1.41	1.33	-	0.99	-	1.33
Joy/Like reading		-0.09	1.08	-3.00	3.00	0.24	0.91	-	3.00
Students' expectations of completing ISCED level 5A or 6	"0 = not checked" "1 = checked"	0.81	0.40	0.00	1.00	0.79	0.41	0.00	1.00
Student's expected occupational status		66.6 7	18.6 4	11.0 1	88.9 6	62.0 2	18.7 6	11.0 1	88.9 6
Self-concept of reading: Perception of competence	<i>d.v.</i>	0.26	1.00	-2.44	1.88	-	0.95	-	1.88
Self-concept of reading: Perception of difficulty		0.08	1.02	-1.89	2.78	0.20	0.97	-	2.78
Perception of difficulty of the PISA test		-0.05	1.00	-1.27	3.01	0.07	1.05	-	3.01

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The degree of efforts that students put into this test	"1=1"~"10=10"	8.25	1.53	1.00	10.0 0	8.25	1.92	1.00	10.0 0
The degree of efforts that students have invested		9.44	1.15	1.00	10.0 0	9.08	1.63	1.00	10.0 0
Feeling: Afraid		2.29	0.84	1.00	4.00	2.85	0.87	1.00	4.00
Feeling: Scared		2.34	0.80	1.00	4.00	2.42	0.86	1.00	4.00
Feeling: Lively	"1 = never"	3.10	0.77	1.00	4.00	3.21	0.80	1.00	4.00
Feeling: Sad	~	2.66	0.78	1.00	4.00	2.51	0.82	1.00	4.00
Feeling: Proud	"4 = always"	3.01	0.75	1.00	4.00	2.81	0.87	1.00	4.00
Feeling: Miserable		2.26	0.86	1.00	4.00	2.00	0.90	1.00	4.00
Subjective well-being: Positive affect		-0.12	1.01	-3.07	1.24	0.03	1.05	-3.07	1.24
Mastery goal orientation	<i>d.v.</i>	0.30	1.02	-3.00	2.00	0.06	1.08	-3.00	2.00
General fear of failure		0.15	1.08	-2.00	2.00	0.19	0.96	-1.89	1.89
Eudaemonia: meaning in life		0.12	1.03	-2.15	1.74	0.09	0.97	-2.15	1.74
Resilience		0.18	1.01	-3.17	2.37	-0.04	1.00	-3.17	2.37
Fixed mindset	"1 = strongly disagree"~ "4 = strongly agree"	2.12	0.95	1.00	4.00	2.42	0.86	1.00	4.00
<i>ICT-related variables</i>									
Interest in ICT		0.09	0.97	-3.00	3.00	-0.11	0.97	-2.93	2.62
ICT resources		0.16	1.13	-3.97	3.60	-0.35	0.79	-3.77	3.60
Perceived ICT competence		0.13	0.93	-3.00	2.00	-0.32	0.97	-2.60	1.99
Perceived autonomy related to ICT use		-0.05	0.99	-2.51	2.03	-0.21	0.96	-2.51	2.03
Use of ICT outside of school for schoolwork	<i>d.v.</i>	0.24	0.99	-2.00	3.00	-0.03	0.91	-2.00	3.00
ICT available at home		8.41	2.16	0.00	11.00	7.65	2.24	0.00	11.00
ICT available at school		7.20	2.10	0.00	10.00	6.35	2.59	0.00	10.00
ICT usage at school		0.42	0.86	-2.00	3.00	-0.72	1.00	-2.00	3.00
ICT use outside of school for leisure		-0.02	1.04	-4.00	4.00	-0.10	0.84	-4.00	4.00
<i>Students' social environmental variables</i>									
Parents' emotional support		0.08	1.00	-2.45	1.03	0.10	0.91	-2.45	1.03
Teacher-directed instruction		0.13	1.02	-2.94	1.82	0.44	1.07	-2.94	1.82
Teacher support in test language lessons	<i>d.v.</i>	0.12	0.94	-2.71	1.34	0.17	0.92	-2.74	1.34
Perceived feedback		0.29	1.05	-1.64	2.02	0.17	1.17	-1.64	2.02
Disciplinary climate in test language lessons		0.12	1.05	-2.71	2.03	1.07	1.01	-2.71	2.03
The length of text that students had to read for the test language lessons	"1 = one page or less"~ "6 = more than 500 pages"	3.93	1.38	1.00	6.00	2.70	0.97	1.00	6.00
Subjective well-being: Sense of belonging to school	derived variable	-0.24	0.97	-3.24	2.76	0.28	1.05	-3.00	3.00

Perception of cooperation at school		-0.18	0.95	-2.14	1.68	0.16	1.04	-2.14	1.68
Attitude toward school: Learning activities		0.29	0.97	-2.54	1.08	0.08	0.97	-2.54	1.08
Teacher- and school-related									
<i>Teacher-related variable</i>									
Teacher-related variables such as the length of text that students had to read for the lessons	"1 = one page or less"~ "6 = more than 500 pages"	2.68	0.32	1.71	3.75	2.10	0.28	1.50	3.19
<i>School-related variables</i>									
Student behavior hindering learning affecting school climate	<i>d.v.</i>	0.50	0.77	-3.38	2.37	0.05	1.46	-3.38	3.44
Number of available computers per student at modal grade		1.54	1.40	0.10	8.93	0.48	0.61	0.00	3.30
The percentage of students from socioeconomically disadvantaged homes	The percentage of students	44.13	23.95	1.00	100.00	13.06	14.02	0.00	88.00

Note. *d.v.* = derived variables

Students’ reading literacy. As shown in Table 3, students’ background variables, cognitive and affective variables (such as metacognitive, motivation, self-concept, and PISA test related variables), and ICT-related variables (such as interest in ICT and ICT usage of school) were found to be similar in predicting students’ reading literacy for both Korean and U.S. students.

Table 3*Effect of variables on students' reading literacy in the U.S. and South Korea*

Variables	U.S.						Korea					
	Model 1		Model 2		Model 3		Model 1		Model 2		Model 3	
	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
Fixed effect												
Intercept	508.998***	2.873	394.695***	14.691	414.505***	20.204	514.071***	3.606	401.624***	9.831	355.950***	19.249
Student-related												
<i>Students' background variables</i>												
Index of economic, social and cultural status	24.548***	2.039	6.394***	1.562	4.946**	1.578	20.044***	1.725	5.778***	1.392	5.026***	1.377
Grade repetition	-80.029***	4.881	-41.899***	4.298	-42.021***	4.311	-31.435***	5.918	-19.983***	5.020	-20.223***	4.991
<i>Students' cognitive and affective variables</i>												
Meta-cognition: Understanding and remembering			6.881***	1.343	6.856***	1.348			10.838***	1.149	10.764***	1.145
Meta-cognition: Summarizing			12.577***	1.408	12.343***	1.399			15.713***	1.078	15.553***	1.072
Meta-cognition: Assess credibility			23.380***	1.323	23.188***	1.314			16.207***	1.138	16.070***	1.138
Joy/Like reading			7.092***	1.308	7.424***	1.288			6.803***	1.339	6.767***	1.327
Students' expectations of completing ISCED level 5A or 6			22.216***	3.546	21.876***	3.534			17.806***	2.614	16.487***	2.631
Student's expected occupational status			0.254***	0.063	0.257***	0.063			0.442***	0.055	0.429***	0.054
Self-concept of reading: Perception of competence			7.655***	1.575	7.825***	1.564			10.272***	1.310	10.392***	1.312

Self-concept of reading: Perception of difficulty	-1.536	1.580	-1.487	1.567	-0.909	1.23 3	-0.984	1.223
Perception of difficulty of the PISA test	-16.828***	1.593	-16.997***	1.582	-12.840***	1.13 1	-12.777***	1.123
The degree of efforts that students put into this test	4.554***	0.959	4.685***	0.959	3.886***	0.65 4	3.953***	0.663
The degree of efforts that students have invested	5.586***	1.282	5.436***	1.290	5.466***	0.72 9	5.415***	0.732
General fear of failure	7.519***	1.205	7.140***	1.208	4.617***	1.08 2	4.544***	1.085
Fixed mindset	-10.278***	1.424	-10.154***	1.410	0.138	1.27 8	0.050	1.274
<i>ICT-related variables</i>								
Interest in ICT	7.939***	1.383	7.924***	1.379	5.023***	1.10 8	4.935***	1.105
ICT usage at school	-9.536***	1.582	-9.504***	1.571	-8.306***	1.10 1	-8.174***	1.069
ICT use outside of school for leisure	-2.424	1.442	-2.252	1.438	-0.342	1.39 8	-0.297	1.395
ICT available at school	-2.230***	0.590	-2.201***	0.592	0.208	0.44 9	0.208	0.444
<i>Students' social environmental variables</i>								
The length of text that students had to read for the test language lessons	6.411***	1.019	5.884***	1.009	-1.966	1.07 7	-2.272*	1.069
Disciplinary climate in test language lessons	5.162***	1.244	5.054***	1.224	-0.512	1.04 7	-0.614	1.035
Teacher- and school-related								
<i>Teacher-related variables</i>								
Teacher-related variables such as the length of text that students had to read for the lessons			1.593	4.425			26.723**	7.849

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School-related variables

Student behavior hindering learning affecting school climate	-3.241	2.230								-5.202***	1.338
Number of available computers per student at modal grade	-0.907	1.388								-7.049*	3.217
The percentage of students from socioeconomically disadvantaged homes	-0.436***	0.079								-0.267	0.152

Random effect

Within variance	8893.934***	196.076	5463.931***	137.41	5453.935***	136.86	7444.112***	183.697	4733.007***	122	4730.017***	121.83
Between variance	900.488***	152.937	304.654***	76.302	195.589***	55.758	2185.194***	298.130	586.948***	105	373.197***	59.178

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

However, some variables showed different patterns in predicting students’ reading literacy across the two countries. Interestingly, the length of text that students had to read for the test language lessons was statistically positively related to the U.S. students’ reading literacy; however, it was statistically negatively related to Korean students’ reading literacy.

Students’ life satisfaction. As shown in Table 4, students’ background variables (such as gender), cognitive and affective variables (such as emotion and motivation-related variables), and students’ social environmental variables (such as parents’ emotional support and attitude toward learning activities at school) were found to be related to students’ life satisfaction for both Korean and U.S. students.

Table 4
Effect of variables on students’ life satisfaction in U.S. and South Korea

Variables	U.S.				Korea			
	Model 1		Model 2		Model 1		Model 2	
	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.	Coeff.	S.E.
Fixed effect								
Intercept	7.001***	0.065	7.154***	0.278	6.950***	0.057	6.970***	0.220
Student-related								
<i>Students’ background variables</i>								
Student gender	0.551***	0.085	-0.204**	0.064	0.968***	0.075	-0.351***	0.048
Index of economic, social and cultural status	0.259***	0.043	0.081*	0.034	0.192***	0.044	-0.034	0.035
<i>Students’ cognitive and affective variables</i>								
Feeling: Afraid			0.094	0.048			-0.128***	0.035
Feeling: Scared			0.046	0.047			-0.072*	0.036
Feeling: Lively			0.258***	0.050			0.169***	0.041
Feeling: Sad			-0.464***	0.050			-0.279***	0.034
Feeling: Proud			0.365***	0.052			0.439***	0.039
Feeling: Miserable			-0.588***	0.045			-0.387***	0.031
Subjective well-being: Positive affect			0.443***	0.046			0.787***	0.037
Student’s expected occupational status			<0.001	0.002			-0.002	0.001
General fear of failure			-0.074**	0.027			-0.115***	0.027
Eudaemonia: Meaning in life			0.526***	0.037			0.333***	0.030
Mastery goal orientation			-0.040	0.036			0.002	0.026
Resilience			-0.051	0.035			0.004	0.031
<i>ICT-related variables</i>								

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Interest in ICT			-0.038	0.034			-0.055*	0.027
ICT resources			0.052	0.031			0.049	0.032
Use of ICT outside of school for schoolwork			0.054	0.041			0.014	0.033
ICT use outside of school for leisure			-0.059	0.036			-0.020	0.034
ICT usage at school			-0.015	0.044			0.042	0.025
<i>Students' social environmental variables</i>								
Parents' emotional support			0.155***	0.032			0.130***	0.030
Teacher-directed instruction			0.029	0.036			-0.052	0.034
Teacher support in test language lessons			0.165***	0.038			0.013	0.038
Perceived feedback			0.015	0.032			0.078**	0.026
Disciplinary climate in test language lessons			0.002	0.028			0.008	0.025
Subjective well-being: Sense of belonging to school			0.072*	0.029			0.010	0.026
Perception of cooperation at school			-0.015	0.034			0.109***	0.026
Attitude toward school: Learning activities			0.081*	0.033			0.117***	0.029
Random effect								
Within variance	6.242***	0.144	3.240***	0.094	6.454***	0.108	3.098***	0.064
Between variance	0.153**	0.047	0.037	0.019	0.139***	0.033	0.012	0.011

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Some variables, however, showed different patterns in predicting students' life satisfaction across the two countries. A high ESCS index was statistically associated with higher life satisfaction in the U.S. only. However, the following variables were statistically negatively significant for Korean students only: feeling 'afraid', feeling 'scared' and ICT interest. Additionally, Korean students' perception of cooperation at school was positively associated with students' life satisfaction.

Discussion

Students' reading literacy and life satisfaction are important indicators of quality of their lives. The current study applies a random forest, which enables

the derivation of key variables from hundreds of variables in the PISA 2018 that might have been overlooked in the previous literature such as usage of long text in class and ICT-related variables. The current study compares the similarities and differences in the key variables derived from random forest and tests the significance of the key variables on reading literacy and life satisfaction in the U.S. and Korea by multilevel modeling. This section discussed the findings of the current study compared to those of previous studies. Moreover, we stress the findings from the current study, which have not been discussed in the previous literature, by integrating machine learning and statistical approaches as follows.

Reading Literacy

As with previous studies, for both the U.S. and Korean students, the current study confirmed the statistically positive effect of ESCS on reading literacy, which has also been supported in the literature (Shin et al., 2013). Additionally, students' metacognitive, motivation and self-concept-related variables were associated with their reading literacy for both the U.S. and Korean students. These results are also congruent with those of previous studies (e.g., Gamazo & Martínez-Abad, 2020; Lim & Jung, 2019).

Interestingly, general fear of failure was positively associated with the reading literacy of students from both countries. Nakhla (2019), similarly, reported a positive relationship between the fear of failure and extrinsic motivation of undergraduate students in the United Kingdom, indicating that even small levels of fear of failure can predict certain types of academic motivation. Furthermore, students' interest in ICT was positively related to reading literacy in both countries. Therefore, ICT should be used meaningfully in educational environments (Hu et al., 2018).

From the random forest analysis, the usage of long text in class was newly derived as a key variable on reading literacy that was not presented in previous studies. With further multilevel modeling analysis, the impacts of the usage of long text in class were somewhat different between the U.S. and Korea. When longer texts were used in class, the U.S. students' reading literacy was higher, while it was lower for the Korean students. This could be explained by the different methods of long text usage during class between the two countries. For example, Korean students are required to answer several

multiple-choice questions using long text within a limited time in class, while U.S. students are typically trained to write an essay in a more flexible manner.

Life Satisfaction

Similar to previous studies, student-related variables, such as students' background, cognitive and affective, or students' social environmental variables, but not the teacher- and school-related variables, were the key variables predicting life satisfaction in the U.S. and Korean students. For both the U.S. and Korean students, general fear of failure was negatively related to life satisfaction. This result differs from that of a previous study by [Eliot et al. \(2001\)](#), in which avoidance goals due to fear of failure were a negative predictor of subjective well-being in individualistic countries, such as the U.S., but not collectivistic countries, such as Korea.

Instead, unlike the U.S. students, the Korean students' negative feelings, such as feeling 'afraid' and 'scared', were found to be statistically significant key variables of life satisfaction. This result indicates a difference in the emotional and psychological aspects that predict overall life satisfaction in U.S. and Korean students. [Yoon and Järvinen's study \(2016\)](#) also reported that students raised in more restraint-oriented Asian countries tend to feel more afraid and/or scared.

In terms of the differences, a sense of belonging at school was statistically positively related only to the U.S. students' life satisfaction. Various reasons could explain the differences between the U.S. as an individual-oriented country and Korea as a social-oriented country. U.S. students' lower level of life satisfaction could be somewhat explained by their lower sense of belonging at school. Interestingly, the relationship between a higher perception of cooperation at school and higher life satisfaction was found only for the Korean students. A cooperative school atmosphere is an important factor in the life satisfaction of Korean students who have a high level of perception of cooperation ([Rudolf, 2020](#)).

Notably, from the random forest analysis, several students' ICT-related variables were derived as key variables of life satisfaction. However, most of the derived ICT-related variables from random forest analysis were not statistically significant after controlling for the other variables through multilevel modeling. The results indicate that ICT-related variables might be highly correlated with other independent variables. Additional correlation

analyses among predictors derived from the random forest methods were conducted, and a surprisingly high correlation between socioeconomic status and ICT resources at home was found in both the U.S. (e.g., $r_{\text{ESCS and ICT resource}} = .603$ and $r_{\text{family wealth and ICT resource}} = .845$) and South Korea (e.g., $r_{\text{ESCS and ICT resource}} = .546$ and $r_{\text{family wealth and ICT resource}} = .690$).

Conclusion and Future Directions

The current study is meaningful in that it demonstrates a flexible way to combine machine learning and traditional statistical methods to explore the key variables among hundreds of variables in the PISA and test the impact of the key variables on reading literacy and life satisfaction. By applying a random forest method, a machine learning technique, the current study revealed predictors of reading literacy or life satisfaction that have not been identified as important predictors in previous literature. As a follow-up, multilevel modeling was applied to test the impact of these predictors on reading literacy and life satisfaction in more detail using the PISA 2018, international large-scale data for an international comparison between U.S. and South Korea.

Machine learning is effective for deriving key variables, while statistical modeling is useful for inferential decision making. This study used random forest analysis, which is a simple and frequently used machine learning technique in educational research. The current study chose multilevel modeling, which is known as a statistical method for clustered data. The current study is meaningful in terms of integrating both machine learning and statistical methods for international comparisons between the U.S. and South Korea using the PISA 2018 dataset.

Recently, several machine learning techniques have been introduced and compared in terms of accuracy and selection of key variables (e.g., [Chen et al., 2020](#); [Liu & Chen, 2017](#), [Sothe et al., 2020](#)). Thus, it is suggested that future studies compare model accuracy and the selection of key variables across diverse machine learning techniques for international comparisons using large-scale data.

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Appendix

Predictors

Level	Variable	Item code	Questionnaire (page number in technique report)	
Student-related	Students' background variables	Age	AGE	ST003 (p. 11)
		Mother's education	MISCED_D	ST005, ST006 (p. 11)
		Father's education	FISCED_D	ST007, ST008 (p. 11)
		Highest education of parents	HISCED_D	ST005- ST008 (p. 12)
		Index of economic, social and cultural status	ESCS	ST005, ST006, ST007, ST008, ST011, ST012, ST013, ST014, ST015 (p. 39)
		<i>d.v.</i> Cultural possessions at home	CULTPOSS	ST011, ST012 (pp. 14-15)
		Family wealth	WEALTH	(pp. 14-15)
		ICT resources	ICTRES	
		Home educational resources	HEDRES	ST011 (pp. 14-15)
		ISEI of mother	BMMJ1	ST014 (p. 12)
	ISEI of father	BFMJ2	ST015 (p. 12)	
	Duration in early childhood education and care	DURECEC	ST125, ST126 (p. 13)	
	Grade repetition	REPEAT	ST127 (p. 13)	
	<i>q</i>	Student gender (0=male, 1=female) and additional 6 variables.	ST004D01T	
	Students' cognitive and affective variables	<i>d.v.</i>	Learning time (minutes per week)	LMINS
Student's expected occupational status		BSMJ	ST114 (p. 13)	
Joy/Like reading		JOYREAD	ST160 (p. 17)	
Self-concept of reading: Perception of competence		SCREADCOM P	ST161 (p. 17)	
Self-concept of reading: Perception of difficulty		SCREADDIFF		
Perception of difficulty of the PISA test		PISADIFF	ST163 (p. 17)	
Meta-cognition: Understanding and remembering		UNDREM	ST164 (p. 13)	
Meta-cognition: Summarizing		METASUM	ST165 (p. 13)	

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		Meta-cognition: Assess credibility	METASPAM	ST166 (p. 13)
		Work mastery	WORKMAST	ST182 (p. 18)
		General fear of failure	GFOFAIL	ST183 (p. 18)
		Eudaimonia: Meaning in life	EUDMO	ST185 (p. 19)
		Subjective well-being: Positive affect	SWBP	ST186 (p. 20)
		Resilience	RESILIENCE	ST188 (p. 18)
		Mastery goal orientation	MASTGOAL	ST208 (p. 18)
	<i>q</i>	How often do you read these materials because you want to? Magazines and additional 22 variables.	ST167Q01IA	
ICT-related variables	<i>d.v.</i>	ICT available at home	ICTHOME	IC001 (p. 26)
		ICT use outside of school (leisure)	ENTUSE	IC008 (p. 26)
		ICT available at school	ICTSCH	IC009 (p. 26)
		Use of ICT outside of school (for school work activities)	HOMESCH	IC010 (p. 26)
		ICT usage at school	USESCH	IC011 (p. 26)
		Interest in ICT	INTICT	IC013 (p. 27)
		Perceived ICT competence	COMPICIT	IC014 (p. 27)
		Perceived autonomy related to ICT use	AUTICT	IC015 (p. 27)
		ICT as a topic in social interaction	SOIAICT	IC016 (p. 27)
		Subject-related ICT use during lessons	ICTCLASS	IC150 (p. 27)
		Subject-related ICT use outside of lessons	ICTOUTSIDE	IC151 (p. 27)
	<i>q</i>	How old were you when you first used a digital device? and additional 11 variables.	IC002Q01HA	
Social environmental variables	<i>d.v.</i>	Subjective well-being: Sense of belonging to school	BELONG	ST034 (p. 22)
		Attitude toward school: Learning activities	ATTLNACT	ST036 (p. 18)
		Disciplinary climate in test language lessons	DISCLIMA	ST097 (p. 15)
		Teacher support in test language lessons	TEACHSUP	ST100 (p. 16)
		Teacher-directed instruction	DIRINS	ST102 (p. 16)
		Perceived feedback	PERFEED	ST104 (p. 16)
		Parents' emotional support	EMOSUPS	ST123 (p. 19)

		Teacher's stimulation of reading engagement perceived by student	STIMREAD	ST152 (p. 16)	
		Competitiveness	COMPETE	ST181 (p. 18)	
		Perception of competitiveness at school	PERCOMP	ST205 (p. 19)	
		Perception of cooperation at school	PERCOOP	ST206 (p. 19)	
		Adaptation of instruction	ADAPTIVITY	ST212 (p. 16)	
		Perceived teacher's interest	TEACHINT	ST213 (p. 16)	
	<i>q</i>	During the past 12 months, how often: Other students took away or destroyed things that belonged to me. and additional 36 variables.	ST038Q06NA		
Teacher- and School-related	<i>d.v.</i>	Teacher employment time - dichotomous	EMPLTIM	TC005 (p. 34)	
		Originally trained teacher (strict definition)	OTT1	TC014, TC015 (p. 34)	
		Originally trained teacher (wide definition)	OTT2		
		Opportunity to learn aspects of reading comprehension	TCOTLCOMP	TC155 (p. 36)	
		Teacher's satisfaction with the current job environment	SATJOB	TC198 (p. 36)	
			Teacher's satisfaction with teaching profession	SATTEACH	TC198 (p. 36)
	<i>q</i>	How old are you? and additional 73 variables.	TC002Q01NA		
	<i>d.v.</i>	School size	SCHSIZE	SC002 (p. 23)	
		Student-teacher ratio	STRATIO	SC002, SC018 (p. 24)	
		Number of available computers per student at modal grade	RATCMP1	SC004 (p. 23)	
Proportion of available computers that are connected to the internet		RATCMP2	SC004 (p. 23)		
School type		SCHLTYPE	SC013, SC016 (p. 24)		
Shortage of educational staff		STAFFSHORT	SC017 (p. 25)		
Shortage of educational material		EDUSHORT	SC017 (p. 25)		
Total number of all teachers at school		TOTAT	SC018 (p. 24)		
Index proportion of all teachers ISCED level 5A bachelor	PROAT5AB				

	Index proportion of all teachers ISCED level 5A master	PROAT5AM	
	Index proportion of all teachers ISCED level 6	PROAT6	
	Index proportion of all teachers fully certified	PROATCE	
	Creative extracurricular activities	CREACTIV	SC053 (p. 24)
	Student behavior hindering learning affecting school climate	STUBEHA	SC061 (p. 25)
	Teacher behavior hindering learning	TEACHBEHA	
<i>q</i>	Which of the following definitions best describes the community in which your school is located? and additional 78 variables.	SC001Q01TA	

Note: d.v. = derived variable; q = questionnaire; T.R. = technique report; Derived variables from questionnaire are described in the technique report (see Chapter 16) (OECD, 2019a)

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