



Exploring the Relationship between Empathy and Innovation amongst Engineering Students

Mr. Justin L Hess, Purdue University, West Lafayette

Justin Hess is a Ph.D. candidate at Purdue University's School of Engineering Education, Masters student in the School of Civil Engineering and a National Science Foundation Graduate Research Fellow. He received his Bachelor's of Science in Civil Engineering in 2011 with a minor in philosophy and anticipates receiving his MSCE in 2015, both from Purdue University. His research focuses on understanding engineers' core values, dispositions, and worldviews. His dissertation focuses on conceptualizations, the importance of, and methods to teach empathy to engineering students. He is currently the Education Director for Engineers for a Sustainable World and an assistant editor for Engineering Studies.

Mr. Nicholas D. Fila, Purdue University

Nicholas D. Fila is a Ph.D. student in the School of Engineering Education at Purdue University. He earned a B.S. in Electrical Engineering and a M.S. in Electrical and Computer Engineering from the University of Illinois at Urbana-Champaign. His current research interests include innovation, empathy, and engineering design.

Dr. Senay Purzer, Purdue University, West Lafayette

enay Purzer is an Assistant Professor in the School of Engineering Education. She is the recipient of a 2012 NSF CAREER award, which examines how engineering students approach innovation. She serves on the editorial boards of Science Education and the Journal of Pre-College Engineering Education (JPEER). She received a B.S.E with distinction in Engineering in 2009 and a B.S. degree in Physics Education in 1999. Her M.A. and Ph.D. degrees are in Science Education from Arizona State University earned in 2002 and 2008, respectively.

Dr. Johannes Strobel, Texas A&M University

Dr. Johannes Strobel is Director, Educational Outreach Programs and Associate Professor, Engineering & Education at Texas A&M, College Station. He received his M.Ed. and Ph.D. in Information Science & Learning Technologies from the University of Missouri. His research/teaching focuses on engineering as an innovation in pK-12 education, policy of STEM education, how to support teachers and students' academic achievements through engineering, engineering 'habits of mind' and empathy and care in engineering. He has published more than 140 journal articles and proceedings papers in engineering education and educational technology and is the inaugural editor for the Journal of Pre-College Engineering Education Research.

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Introduction

Innovation has been described as an important and even essential skill for an individual to succeed as a practicing engineer in today's ever-growing, competitive, and global economy.^{1,2} The United States' Council on Competitiveness wrote in 2005, "Innovation will be the single most important factor in determining America's success through the 21st century".^{3, (p. 7)} The word "innovation" has become a buzz-word of sorts throughout the engineering education research community, where the foci ranges from reshaping the engineering curriculum itself⁴ to looking at the diffusion of innovative course offerings⁵.

What we focus on in this study is skills required for an engineering student to be innovative, what we call innovative design. We describe innovative design as the act of generating novel concepts, processes, or designs. Innovative design is closely linked to creativity,⁶ using and implementing creative ideas to develop something tangible, real, or meaningful in a societal context. This type of innovation may be described as incremental, leading to small changes, or radical, leading to a complete rethinking of existing practices and designs, or generating entirely new concepts altogether.⁷

Innovative design may be broken up into constituent components by identifying what skills or traits are necessary for being innovative. For example, Eris (2004) focused on the role of effective inquiry through generative design questioning in stimulating ideas for innovation.⁸ The Innovator's DNA, on the other hand, thematically developed a series of skills or behavioral tendencies successful innovators held in common, noting that innovators varied in their capacity for each of these skills but tended to at least be high in two or more of these. According to the Innovator's DNA, these innovative behaviors include questioning, idea networking, experimenting, observation, and associative thinking.⁹ Dyer, Gregersen, and Christensen (2008) used this framework to develop a self-report instrument that measures an individual's tendency to practice the first four of these innovative behaviors.¹⁰

As the focus on innovation within engineering education grows, there is a parallel emerging body of knowledge on empathic design.¹¹ In their novel albeit seminal work on empathic design, Leonard and Rayport (1997) suggested empathic design may be the key to sparking innovative design.¹² Similarly, observation was a key skill or behavior exhibited by innovators as identified by Dyer, Gregerson, and Christensen.¹⁰ In the Innovator's DNA, these same authors suggested empathy was central not only for observation, but also questioning, writing "innovators inquire deeply for answers about what is happening right here and right now to gain understanding and empathy for others' experience"^{9,p. 74}. In other words, empathy seems either correlative or core to these distinct innovative behaviors.

Research Purpose

This paper explores whether a specific trait or tendency may be connected to innovation: empathy. This quantitative study is guided by the following research questions:

RQ1: What is the relationship between the empathy and innovation amongst engineering students?

RQ2: To what extent are empathic tendencies predictive of innovative behavioral tendencies?

Using a model developed out of social psychology,¹³ we define empathy as a multi-faceted phenomenon built upon four distinct sub-constructs: (a) *fantasy*, (b) *perspective-taking*, (c) *empathic concern*, and (d) *personal distress*. Here we explore whether any or all of these components of empathy, as measured using the Interpersonal Reactivity Index developed by Mark H. Davis,¹⁴ are related to any of the innovative behaviors measured in Dyer, Gregersen, and Christensen's (2008) Innovative Behaviors Scale.¹⁰ These instruments and their sub-scales are identified and described briefly in the following sub-sections.

Innovative Behavior Scales

- **Questioning:** Asking questions in order to challenge inherent assumptions and increase understanding of a topic or context.
- **Networking:** Interacting with people from diverse backgrounds to gain new perspectives and develop, refine, and test ideas.
- **Experimenting:** Seeking and exploring new experiences and surroundings to expand knowledge and testing new ideas mentally or physically.
- **Observing:** Carefully and critically examining the everyday world to understand how objects and systems function and are used.

Interpersonal Reactivity Index Scales

- **Fantasy:** The tendency to imagine oneself in another's position, in particular, fictional characters featured in books or movies.
- **Perspective-Taking:** A tendency to imagine how another is thinking or feeling.
- **Empathic Concern:** A tendency to have other-oriented feelings of concern, or sympathy.
- **Personal Distress:** A tendency to have self-oriented emotive feelings as a result of tense interpersonal situations.

Data Collection

As a data collection strategy, we invited students at a large Mid-Western University to complete each of two surveys: (a) the Interpersonal Reactivity Index and (b) the Innovative Behavior Scales. We reached out to each of the survey designers for permission in applying these instruments. At the end of the survey students had the opportunity to volunteer in a follow-up interview by providing their name and e-mail. The survey commenced with a series of demographic questions, including age, gender, academic status, and engineering major. The Interpersonal Reactivity Index contained 28 self-report questions along four sub-scales whereas the Innovative Behavior Scales contained 19 questions along 4 sub-scales. For each question,

students could respond along a 5-point Likert scale where 1 was equal to “Does not describe me well” and 5 was equal to “Describes me very well”.

Our participants were from various engineering disciplines at a large Mid-Western University. The survey was disseminated to participants at the beginning of the Spring 2014 semester using administrative points of contacts through a number of engineering list-servs, some disciplinary (e.g. Mechanical, Civil) and some organizational (e.g. Society of Women Engineers, Engineers for a Sustainable World). Participants were provided no monetary incentive for completing these surveys, although they had the opportunity to volunteer in a follow-up interview that compensated \$10.

As of February 21, 2014, 220 individuals had opened the survey, of which 148 complete survey responses were collected. We removed any individual who did not answer every survey-item. The majority of respondents spent less than 10 minutes to complete all questions. This sample included 82 males, 65 females, and one participant who preferred not to identify by gender. Four individuals were 18-19 years of age, 104 were 20-25 years of age, 25 were 25-26 years old, and 15 students were older than 30. The sample included 14 sophomores, 23 juniors, 25 seniors, 30 Masters students, 55 PhD students, and 1 student who listed “other”. Participants’ engineering majors are listed in Table 1. It should be noted that our access to certain list-servs influenced the distribution represented herein, rather than the distribution of students represented at the Large Mid-Western University these participants attended. The “Other” category included participants from Biomedical, Agricultural and Biological, Construction Engineering Management, Environmental and Ecological, Mechanical, and Multidisciplinary Engineering.

Table 1: Participant distribution by engineering discipline

Engineering Discipline	Frequency	Relative Percentage
Aeronautical and Astronautical Engineering	16	10.8
Chemical Engineering	23	15.5
Civil Engineering	21	14.2
Electrical and Computer Engineering	26	17.6
Engineering Education	13	8.8
Industrial Engineering	23	15.5
Nuclear Engineering	15	10.1
Other	11	7.4

Data Analysis

This study includes an analysis of the correlation between each of the survey scales from the Interpersonal Reactivity Index and Innovative Behavior Scales and a linear regression of these empathic tendencies against a single innovative behavior measure that we called *Discovery*. These results are used to explore each individual empathic tendency’s relationship with innovation in greater detail, and to provide insights on what empathic dispositions engineering educators may wish to focus on if the primary goal is to promote specific innovative behaviors amongst their students.

Results

In this study, we have quantitatively explored what relationship the four distinct sub-constructs of empathy, as measured using the Interpersonal Reactivity Index¹⁴ (Perspective-Taking, Empathic Concern, Personal Distress, and Fantasy) showed with the four innovative behavior traits as measured using the Innovative Behavior Scales¹⁰ (Questioning, Idea Networking, Experimenting, or Observation). Table 2 provides a descriptive overview of the respondents' scores across individual survey measures.

Table 2: Descriptive statistics across empathy and innovation survey scales

		All Respondents (n = 148)		Males (n = 82)		Females (n = 65)	
	Survey Scale	Mean	σ	Mean	σ	Mean	σ
Empathy Scales	<i>Fantasy (FS)</i>	3.48	0.80	3.29	0.85	3.73	0.65
	<i>Perspective-Taking</i>	3.65	0.58	3.69	0.60	3.60	0.56
	<i>Empathic Concern</i>	3.68	0.69	3.63	0.70	3.76	0.68
	<i>Personal Distress</i>	2.48	0.65	2.41	0.61	2.60	0.67
Innovation Scales	<i>Questioning</i>	3.60	0.80	3.68	0.76	3.49	0.84
	<i>Observing</i>	3.55	0.83	3.61	0.83	3.48	0.83
	<i>Experimenting</i>	3.65	0.79	3.78	0.78	3.49	0.78
	<i>Idea Networking</i>	2.89	0.92	2.82	0.90	2.97	0.95

Note. Mean scores correspond to a 5-point Likert scale where 1 = “Does not describe me well” and 5 = “Describes me very well”

Table 3 displays the correlations between the separate Interpersonal Reactivity Index sub-scales, the Innovative Behavior sub-scales, and the correlations between these two subscales. The area highlighted in blue depicts these cross-instrument correlations.

While these correlations show the relationship between survey scales, they do not indicate to what extent the empathic tendencies predict innovative behaviors, or vice versa. The empathy measures are considered to measure distinct components of empathy, wherein theoretically the scales cannot be merged to create a single empathy score. As proof of this theory, the reliability across the 4 survey measures is well below minimal acceptability ($\alpha = 0.398$). As Table 3 shows, the only significant correlations between empathy measures were found between Empathic Concern and Fantasy and Empathic Concern and Perspective-Taking. On the other hand, the innovative behaviors were internally consistent, suggesting they can possibly be mapped to a single score. With our 148 respondents, the relationship between the innovative behavior scales proved to be excellent in terms of internal consistency reliability ($\alpha = 0.798$).

Table 3: Relationship between *empathic tendencies* and *innovative behaviors*

	Questioning	Observation	Experimenting	Idea Networking
Fantasy	0.199*	0.194*	0.089	0.063
Perspective Taking	0.280**	0.332**	0.282**	0.153
Empathic Concern	0.240**	0.224**	0.066	0.234**
Personal Distress	-0.246**	-0.245**	-0.264**	-0.229**

Note. The section highlighted in blue represents correlations across the two survey instruments. The sample size consists of 148 respondents. A correlation of 0.1 represents a “small” effect size, 0.3 represents a “medium” effect size, and 0.5 represents a “large” effect size¹⁴.

**Denotes the correlation is significant at the 0.01 level (2-tailed)

*Denotes the correlation is significant at the 0.05 level (2-tailed)

In order to predict the role of these empathic tendencies in leading to innovative behavior, we have combined the innovation scales into a single measure we have called “Discovery”. However, it is important to note that while each of the innovative behaviors are seen as influential to discovery behavior, the Innovators DNA recognized that innovators do not generally practice all of the behaviors but rather some subset of the behaviors. Further, they seemed to suggest that Observation may be the most influential for discovery behavior, whereas Idea Networking may be the least. Nonetheless, when creating this Discovery measure, we assumed that all of the innovative behaviors are equally influential in leading to discovery, and therefore an individual whose average score across the 4 innovative behaviors was moderate thereby scored higher than in individual who scored very well in one behavior but poorly across the other 3.

In Table 4, we present the results of a Linear Regression modeling Discovery as a dependent variable against the empathy scales. In order to perform linear regression, the following assumptions were met. An examination of the scatterplot of the dependent variable against each independent variable showed each relationship to be approximately linear. The Durbin-Watson statistic for this linear regression was equal to 2.035, indicating that the residuals were independent. The best-fit line through the scatterplot of the independent variable showed it to be homoscedastic. Lastly, the Normal PP-Plot showed that the distribution of the residuals was approximately normal.

While all of these assumptions for linear regression were met, one assumption was not, as there were 2 outliers found in the data. In one of these instances the individual scored highly on discovery skills at 4.71 and in another where the individual scored very low at 1.88. For each of these responses, the predicted value was 2.88 and 3.71, respectively. This indicates that there are cases where an individual is highly empathic but does not exhibit innovative behaviors, and cases where an individual is highly innovative but non-empathic. As there were only two, these outliers were retained in our regression model, although it should be noted that each could significantly impact the estimated parameters. However, since the outliers were in opposite directions, it is likely that their influences on the estimated parameters are somewhat mitigated by one another.

Table 4: Linear regression results of empathy scales against *discovery behavior*

Variable	Estimated Parameter	t statistic	Sig.
Constant	1.450	5.025	.000
Fantasy	0.125	2.032	.044
Perspective-Taking	0.291	3.306	.001
Empathic Concern	0.154	2.025	.045
Personal Distress	-0.350	-4.686	.000
Number of observations		148	
R Square		.254	

A hierarchal multiple regression was performed on engineering students' discovery behavior tendency from the four empathy sub-scales in the Interpersonal Reactivity Index. The results of the model are presented in Table 4. This model explained 25.4% of the variance in delinquency ($R^2 = .25$), which was greater than chance alone would predict ($F(4, 148) = 12.02, p < .05$). Each of Fantasy ($b = .125, SE = .061, p < .05$), Perspective-Taking conflict ($b = .291, SE = .088, p < .05$), Empathic Concern ($b = .15, SE = .076, p < .05$), and Personal Distress ($b = -0.350, SE = .075, p < .05$) were significant predictors of Discovery. Increases in Discovery were associated with increases in Fantasy, Perspective-Taking, and Empathic Concern while increases in Personal Distress indicated decreases in Discovery.

The regression equation indicated by this model can be presented functionally as follows:

$\text{Discovery Behavior} = 1.450 + 0.125 (\text{Fantasy}) + 0.291 (\text{Perspective-Taking}) + 0.154 (\text{Empathic Concern}) - 0.350 (\text{Personal Distress})$

Discussion

Each scale from the Interpersonal Reactivity Index demonstrated a significant relationship with two or more measures from the Innovative Behavior Scales, suggesting there is a close relationship between the two constructs amongst engineering students. The strongest correlations were between Perspective-Taking and the innovative behaviors (for example the relationship between Perspective-Taking and Observation held the only Pearson's r correlation above .3). Personal Distress, a measure of one's tendency to become tense in specific interpersonal situations, demonstrated statistically significant correlations to all innovative behaviors, with each correlation being *negative*. While many other relationships between the survey scales proved to be significant, it should be noted that no relationships were above the 0.50 threshold indicating a large effect size, and only one correlation was above the 0.30 threshold for a medium effect size.¹⁵

The results from the linear regression indicated that each empathic tendency was predictive of discovery behavior. The empathy scale with the largest influence in terms of magnitude was Personal Distress, which negatively influenced Discovery behavior. Each of the other empathic

tendencies positively predicted Discovery, with the most significant of these positive predictive empathic tendencies being Perspective-Taking.

For clarity and ease of interpretation, in the following sections we examined the results for each single measure from the Interpersonal Reactivity Index in light of the correlations and linear regression results. We begin with each of the positive predictors and end with the sole negative predictor.

Perspective-Taking

Perspective-Taking had the second highest mean score of the empathy measures ($\mu = 3.65$), with males scoring slightly higher than females ($\mu_{\text{males}} = 3.69$ and $\mu_{\text{females}} = 3.60$). Results from the linear regression indicated that for each one point increase in Perspective-Taking, on average, an individual's Discovery behavior increased by 0.291 points along the 5-point Likert scale. The correlations between Perspective-Taking and the individual innovation behaviors indicated that Perspective-Taking was most highly correlated with Observation ($r = .332$), followed by Experimenting ($r = .282$) and Questioning ($r = .280$). The only non-significant relationship was found between Perspective-Taking and Idea Networking.

The strength of the relationship between Perspective-Taking and Observation is broadly supported by the literature on empathic design, where the explicit focus is commonly on observing users in the real-world alongside a consideration of those users' perspectives throughout the design process.¹² Yet, the strong relationship with Discovery behavior is also heavily influenced by Perspective-Taking's relationship with Experimenting and Questioning behavioral tendencies. While the pathway is unclear, we suggest Perspective-Taking plays the ameliorative role in catalyzing novel inquiries and, in particular for engineers, motivates them to test potential solutions experimentally either cognitively or through physical creation or manipulation of artifacts. Taken together, this other-oriented ethos leads to innovative designs. Surprisingly, Perspective-Taking was *not* strongly related to Idea Networking. Perhaps it is because the items of this scale are more self-oriented (e.g. what can "I" learn) than the other-oriented nature of the Perspective-Taking scale. Or perhaps it is because these items involve direct communication, where perspectives are shared verbally, and a cognitive exploration of another's perspective may be unneeded as it is explicitly shared by the other.

Empathic Concern

Respondents scored highest on Empathic Concern of all survey measures ($\mu = 3.68$). On average, males scored 3.63 and females scored 3.76. Results from the linear regression indicated that for each one point increase in Empathic Concern, an individual's Discovery behavior increased by 0.154 points, on average. This impact on Discovery behavior was roughly half that of Perspective-Taking. The correlations between Empathic Concern and the individual innovation behaviors indicated that Empathic Concern was most highly correlated with Questioning ($r = .240$), followed closely by Idea Networking ($r = .234$) and Observation ($r = .224$). The only non-significant relationship was found between Empathic Concern and Experimenting.

Based off our previous work, we posit that empathic concern inspires a motivation on part of the engineer or designer to deliver optimal results to the end user.¹⁶ This drive leads one to implement a variety of practices or techniques, in particular those that are socially oriented (e.g. questioning the social context, gathering insights from users and fellow engineers, observing the impact of design decisions in a societal context). We hypothesize that the stronger the link between the designer and others, be those ‘others’ users or fellow designers, the stronger the relationship between Discovery and Empathic Concern would become. Indeed, this seems to have happened for students who experienced the highest levels of human-centered design, when the connection between the designer and client becomes more intimate.¹⁷ This hypothesis could be tested in future work where the framing of the questions are differed slightly, ranging from the generality of the empathy items as written currently to specificity where a user with whom the designer is closely connected is described within the empathy items. In addition, to the extent that an engineer experiences a heightened other-orientation with a broad number of stakeholders, a greater diversity of insights would be created through the integration of these others’ diverse perspectives into the design process, thereby bolstering potentially innovative solutions.

Fantasy

Of the empathy measures that positively predicted Discovery behavior, Fantasy had the lowest mean score across survey respondents ($\mu = 3.48$). Interestingly, this was the only mean score that looked to have a significant difference across genders, where the mean score for females ($\mu = 3.73$) was significantly higher than that for males ($\mu = 3.29$). In addition, Fantasy had the smallest influence on Discovery, where results from the linear regression indicated that for each one point increase in Fantasy, on average, an individual’s Discovery behavior increased by 0.125 points. This impact was nearly a third of Perspective-Taking. The correlations between Fantasy and the individual innovation behaviors indicated that Fantasy was significantly correlated with Questioning ($r = .199$), followed by Observation ($r = .194$) at $\alpha = 0.05$.

Within literature on empathic design, the focus on getting designers into situations ‘as if’ they were users is common. As an example, Johnson et al. (2014) developed an “empathic experience design” where the designers are situated within difficult situations that the user may experience with the final design outcome.¹⁸ Their findings indicated that individuals who went through this experience were likely to develop significantly more original product-user interaction features. As a dispositional tendency, if one were prone to imagine oneself in others’ positions they would likely bear an open-mindedness that is central to innovation, thereby enabling the designer to think outside the box and make novel associations. Indeed, in the Innovator’s DNA they suggest some of the most successful innovator’s do just this.⁹

Yet, it is intriguing to note that this Fantasy sub-construct had the lowest predictive relationship with discovery behavior. Our current hypothesis is that the construct’s items focus too much on fictitious situations (e.g. books, movies) than people in the real-world. In other words, we question the implicit assumption that imagining oneself in the role of fictitious characters (e.g. whom the individual reads about or sees in a movie) is directly transferrable to real-world situations (e.g. a designer imaging oneself as a user). In the future, a designer-specific framing of these questions seems needed, where the focus of the items is on real users.

Personal Distress

Personal Distress was the single empathy measure that negatively predicted Discovery behavior, and it likewise had the lowest mean score across survey respondents ($\mu = 2.48$), where females ($\mu = 2.60$) scored slightly higher than males ($\mu = 2.41$). Personal Distress had the largest influence on predicted Discovery behavior, where results from the linear regression indicated that for each one point increase in Personal Distress, on average, an individual's Discovery behavior decreased by 0.350 points. Personal Distress showed a significant negative correlation with each innovative behavior, with Experimenting being the most negative ($r = -.264$) followed by Questioning ($r = -.246$), Observation ($r = -.245$), and Idea Networking ($r = -.229$).

The pervasiveness of this negative relationship is highly intriguing. It is essential to recognize that Personal Distress (the tendency to become anxious in tense situations) is not the same as empathic distress (the tendency to internalize another's emotions without losing sight of the other's thoughts and feelings)¹⁹. In theory, the two are related, but in Hoffman's (2000) model, empathic distress leads to responding behavior *as long as* the distress is not so extreme that one looks inwards instead of outwards. In other words, too much internalization of the other's feelings leads one to become egocentric and thereby react selfishly as opposed to altruistically. This egoistic orientation would hinder all other-oriented empathic tendencies (e.g. Perspective-Taking, Empathic Concern) which would thereby inhibit the previously explored empathy and innovation relationships. Therefore, just a bit of Personal Distress may be helpful for innovation, but for individuals who scored very highly on this scale, it is likely that they stop Observing, Questioning, Idea Networking, and Experimenting when they become overly distressed.

Conclusion and Implications

Results from this study inform the body of engineering education knowledge by generating the first concerted discourse around empathy, innovation, and engineering. Results from this study have indicated which specific components of empathy as measured by the Interpersonal Reactivity Index catalyze or inhibit innovative behavioral tendencies. Using these results, engineering educators interested in promoting innovative behaviors may focus their attention on those empathic tendencies most closely related to the target behavior. The most significant relationship was between Perspective-Taking and Observation, which suggests engineering educators may benefit by finding methods for developing Perspective-Taking tendencies if seeking to promote innovation within human-centered design approaches. As a prerequisite, educators may need to help novice designers identify the key stakeholders involved in the decision, which is an initial tendency that engineers must develop if seeking to apply a wholly empathic design process. Such Perspective-Taking may be contingent upon having a real client to work with (e.g. within project-based learning approaches). Similarly, the other positive links between Empathic Concern, Fantasy, and the innovative behaviors may require the engineer to have mindsets oriented towards *real*-world users who would be impacted by the design.

The pervasive negative relationship between Personal Distress and each innovative behavior seems to be an especially critical area for further investigation. At the individual course level, it suggests that instructors seeking to inspire innovation should emphasize alleviating stress to the extent possible. Fostering an individual instructor's empathic dispositions would seem helpful here, as it would be difficult to expect students to become more empathic if they felt their

instructors were not so. Programmatically and administratively, beyond course instructors, these findings suggest that providing students with support they need throughout all aspects of their education ought to become a central foci, as students often navigate through their academic pathways with unique external factors that induce varying levels of stress.

Limitations

One of the key limitations of this study is that our sample came from one university. In future work, to increase generalizability, these findings should be replicated with a broader sample of students across a broader range of backgrounds across the United States and even worldwide. Yet, we caution the implementation of the surveys verbatim into contexts where the survey respondents may not be comfortable with the English language. Preliminary qualitative responses with some of our participants suggested that some students may have interpreted the phrasing of questions differently than the items were intended. This potential limitation will be further explored in a follow-up qualitative analysis of these post-survey interviews.

A few notes on statistical power are needed. In this study, power represents the probability that the t-test has accurately detected a relationship between two scales that would lead to the rejection of the null hypothesis (e.g. that two scales are *not* related). With a greater sample size, the statistical power also increases. Here a correlation of 0.1 represents a “small” effect size, 0.3 represents a “medium” effect size, and 0.5 represents a “large” effect size¹⁵. According to Cohen (1992), in order to achieve a statistical power of 0.80 when a medium effect size is detected ($r = 0.30$) for $\alpha = 0.01$ at least 125 samples are needed, whereas for $\alpha = 0.05$ at least 85 samples are needed. In contrast, when a small effect size is detected ($r = 0.10$), for $\alpha = 0.01$ at least 1,163 samples are needed, whereas for $\alpha = 0.05$ at least 783 samples are needed. As the majority of the correlations reported in Table 3 are below 0.30, and the sample size is 148, the statistical power for these t-tests at $\alpha = 0.05$ and $\alpha = 0.01$ is well below 0.80. Likewise, as the sample sizes in Table 4 and 82 and 65 for males and females, respectively, for the correlations below 0.30 the statistical power of the t-tests comparing scales is well below 0.80. All of this is to say that by increasing the sample size in future studies, it is possible we will detect relationships between the survey scales that we have perhaps failed to detect here by committing a Type II error.

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