Engineering CAReS: Measuring Basic Psychological Needs in the Engineering Workplace

Prof. Denise Wilson, University of Washington

Denise Wilson is a professor of electrical and computer engineering at the University of Washington, Seattle. Her research interests are split between technical research in sensors and sensor systems and engineering education with an emphasis on the role of self-efficacy, belonging, and other non-cognitive aspects of the engineering classroom and engineering workplace.

Dr. Jennifer J. VanAntwerp, Calvin University

Jennifer J. VanAntwerp is Professor of Engineering at Calvin University in Grand Rapids, Michigan. She earned an M.S. and Ph.D. in Chemical Engineering from the University of Illinois at Urbana-Champaign, with research in protein engineering. Her current research interests include engineering career pathways as well as diversity, equity, inclusion, and belonging, both in engineering education and engineering workplaces.

Ms. Shruti Misra, University of Washington

I am a graduate student in Electrical and Computer Engineering at the University of Washington, Seattle. My research interest is broadly focused on studying innovation in university-industry partnerships. I am interesting in various ways that universities

Engineering CAReS:
Measuring Basic Psychological Needs in the Engineering Workplace

Abstract

Engineering CAReS (Competence, Autonomy, Relatedness Study) is an engineering workplace climate survey that is based on basic psychological needs theory (BPNT) -- a mini-theory associated with self-determination theory (SDT). The CAReS survey uses a combination of existing items and scales from the BPNT and belonging literature as well as items adapted to the workplace setting to measure the degree to which basic psychological needs of autonomy, competence, and relatedness are satisfied or frustrated at work. The CAReS study was initiated at the start of 2022 and Phase 1 of the study, which focused on tool development, was completed in December of 2022.

Over 200 survey responses were collected from engineers working in academic positions, engineers working in non-academic positions, and individuals working closely with engineers. Phase 1 used confirmatory and exploratory factor analyses to develop and refine measurement scales suited to the engineering workplace. Scale refinement also revealed interesting insights regarding how engineers perceive their workplace needs. For instance, scales associated with the satisfaction of relatedness needs that have been validated in previous workplace studies did not demonstrate good fit to the engineering workplace context and had to be discarded. Feelings of being cared for by coworkers and being close to coworkers did not make a suitable construct for measuring relatedness. Instead, belonging scales that explored perceptions of being accepted and supported within a workgroup indicated validity for this study and therefore replaced the satisfaction of relatedness needs as a suitable scale for relatedness.

After confirmatory and exploratory factor analyses were completed, four, three, and two subscales demonstrated sufficient construct validity and reliability to be used to measure relatedness, competence, and autonomy needs, respectively. One subscale (organizational belonging) associated with relatedness needs was eliminated because of its similarity to the occupational belonging subscale. Satisfaction of relatedness needs was eliminated as a subscale due to poor model fit and replaced with a workgroup belonging subscale with better fit.

Altogether, factor analyses of our tool development data generated multiple reliable scales suitable for measuring psychological needs of competence, autonomy, and relatedness. In total, 53 items representing 10 subscales measuring these three psychological needs were reduced to 37 items on 8 subscales which significantly reduced the overall length and average time required to complete the BPNT portion of the survey. The shorter completion time will support the recruitment of a much larger study population among working engineers.

Introduction

A large proportion of research focused on the engineering workplace has sought to identify the barriers and obstacles faced by individuals from under-represented groups (including women) [1]-[4]. This approach is very useful for facilitating specific organizational changes that can reduce or eliminate these barriers. However, complementary research that addresses the psychological impacts of these barriers is lacking. Understanding how and to what degree the psychological needs of working engineers are being met, neglected, or even thwarted, in the workplace can open doors to a broader range of change strategies for retaining diversity and enhancing productivity among engineers.

While many engineering workplace studies focus on what to eliminate in the workplace to better support working engineers, few studies focus on what needs to be added to the workplace. One way to approach this problem of how to supplement workplace culture is to look at the workplace through the lens of psychology. This not only can put a positive spin on workplace culture change (how to make it better instead of how to make it less bad), it also provides a range of options. For example, there may be no accessible solution to increasing job security in some occupations but many ways to better support the autonomy needs of individuals who work in volatile jobs. Thus, developing a means to explore psychological needs among engineers in the workplace opens up opportunities to develop new strategies for building a stronger, healthier workforce with lower turn-over and greater persistence.

To this end, the engineering CAReS study seeks to understand the degree to which basic psychological needs of individuals working in engineering settings are satisfied or frustrated. This paper focuses on developing the instrument (survey) that is central to the CAReS study, specifically on validating survey scales/measures and reducing survey length for broader distribution in the engineering workplace.

Background

This study draws on self-determination theory (SDT) for conceptual framing. SDT is an empirically supported, needs-based perspective on what motivates individuals to behave with willingness and choice rather than acting out of obligation or becoming demotivated altogether. Unlike other needs-based theories, evidence that validates SDT in the workplace is well established [5][6]. Basic psychological needs theory (BPNT) is a component theory of SDT that puts needs for *autonomy*, *competence*, and *relatedness* at the forefront of psychological health and well-being. Workplaces that either provide low support for or actively thwart these needs are logical candidates for high turn-over, dissatisfaction, and poor productivity.

Autonomy: Individuals need to feel they are masters of their own destiny and that what they do has been chosen freely rather than out of a sense of obligation to, or coercion by, external factors. Those whose autonomy needs are satisfied feel that what they are doing is consistent with their core values and life purpose [7]. A deficit autonomy environment either lacks opportunities for pursuing core values and interests or actively blocks this pursuit [8].

Competence: When needs for competence are satisfied, individuals maintain interest, engagement, and attention to tasks, persist in their efforts, and experience personal satisfaction and well-being. In contrast, those who do not feel competent in what they do experience reduced motivation and satisfaction. When tasks are boring or too easy, competence needs go unmet.

When tasks are too challenging or frustrating, guidance is lacking, or job performance is too heavily critiqued or undervalued, competence needs are frustrated or thwarted. Psychologically, individuals seek out the sweet spot between these two extremes – the optimal challenge [6][9].

Relatedness: All individuals have a desire to interact with others, experience connection to them, and feel cared for. This sense of being cared for must be perceived as independent of ulterior motives or alternative agendas. The satisfaction of relatedness needs corresponds to a sense of belonging. In contrast, unfulfilled or thwarted relatedness needs lead to feelings of isolation, stress, and loneliness and are correlated to a wide range of detrimental physical and mental symptoms and illnesses [10].

SDT posits that meeting these basic psychological needs in the workplace leads to more autonomously motivated employees acting out of "... a full sense of volition, willingness, and choice" [5, p.7] as opposed to being controlled (i.e., acting out of obligation) or amotivated (i.e., not motivated to work at all) [5]. Autonomous motivation has two different forms, both of which are supported by the satisfaction of the basic psychological needs. First, employees become more intrinsically motivated when basic psychological needs are met, pursuing their daily work activities out of a sense of enjoyment and interest in those activities. Second, employees who are autonomously motivated internalize extrinsic motivations, such as the values of the organization or of their own workgroup [5]. Both types of autonomous motivation are responsible for improved intentions and behaviors associated with boosting physical health and safety [11], as well as increased persistence, greater satisfaction, and improvements in overall well-being [12][13]. Further Olafsen et al. [14] demonstrated that the satisfaction of basic psychological needs contributes to improvements in autonomous motivation at work over time and not the other way around [14]. In these ways, SDT clearly supports that positive outcomes at work result when basic psychological needs are satisfied and negative outcomes when these needs are frustrated or thwarted. The pathways by which these outcomes are reached may be direct or they may be indirect, but ample empirical evidence exists to validate BPNT within the over-arching context of self-determination theory.

How are basic psychological needs relevant at work?

As early as 1992, empirical evidence for the importance of BPNT at work in the SDT context emerged in the literature. In a study of a work-readiness program at a state psychiatric hospital, Kasser, Davey, & Ryan [15] demonstrated that the satisfaction of psychological needs among workers positively predicted managers' rating of their performance. A year later, in a study of manufacturing workers, basic psychological needs satisfaction was also shown to positively predict job satisfaction and self-esteem [16]. Similar positive outcomes have been demonstrated in a wide range of workplace studies in the twenty-first century. For example, satisfaction of the three basic psychological needs has been clearly linked to greater job satisfaction for employees working in psychiatric facilities [17], better performance evaluations and well-being at work in the high stress world of investment banking [18], greater overall psychological health in government organizations [19], more hours and greater engagement among volunteers at an animal shelter [20], and greater well-being, job performance, and affective commitment to the job for food industry workers [21]. Further, the mere perception that managers support the basic psychological needs of their subordinates has been associated with reduced somatic system burden (i.e., physical symptoms that have no medical explanation but are related to poor quality

of life and disability) [22]. These needs not only play a direct role in influencing work outcomes, but also a mediating role. For instance, Vansteenkiste et al. [23] showed that satisfaction of psychological needs plays an important mediating role in the relationship between the work aspirations of the employee and resulting psychological well-being and work engagement.

Needs for autonomy, competence, and relatedness, however, can have different effects on different outcomes, thus making it important to measure all three needs. Some needs may have no effect at all while others have significant impact. This heterogeneity has been demonstrated in a meta-analysis of BPNT studies by Van Der Broeck et al. [24]. For instance, each of the basic psychological needs was positively associated with job satisfaction, performance measures, work effort, and affective commitment to the job, and negatively associated with turnover intentions. However, only needs for autonomy and relatedness were negatively linked to absenteeism while competence was unrelated [24]. With regard to organizational climate, all three psychological needs were significantly and positively associated with positive leader behavior and perceived organizational support while the fit between employee and work environment was significantly and positively linked only to the satisfaction of autonomy needs [24]. In a more recent study in Australia, satisfaction of autonomy and competence needs were associated with less job ambiguity while relatedness needs were associated with greater resilience at work [25]. In a review of daily diary studies, Coxen et al. [26] confirmed that different outcomes are associated with different needs. Importantly, these authors also highlighted that significant variation within employees over time merits examining needs satisfaction frequently – on a weekly or daily basis.

While ample literature has explored the positive impacts of meeting, and the drawbacks of frustrating, autonomy, competence, and relatedness needs in the workplace, studies of basic psychological needs that focus specifically on STEM are very limited. Furthermore, the studies of needs in the engineering or STEM workplace that have been conducted have not been framed within SDT. For example, the lack of importance that satisfaction or frustration of autonomy needs may play in work outcomes is reinforced by a qualitative study of 1,464 women who left engineering by Fouad et al. [27] which showed that autonomy was infrequently cited as a reason leaving work (only 38 times compared to over 200 times for other reasons for leaving). Although the basic psychological needs were not explicitly assessed in the coding approach for the Fouad study, study participants did refer needs for achievement (i.e., needs to use abilities and advancement -- similar to competence needs) 282 times and to altruism (which included elements of relatedness needs) 239 times. These types of studies are suggestive that basic psychological needs do matter in the workplace and especially so for under-represented groups, but to the best of our knowledge, no studies to date have explicitly explored these needs.

The CAReS study is designed to do fill this gap in the literature and better understand the underlying psychology of working engineers. Do they feel autonomous? Do they feel competent? Do they feel a sense of belonging/relatedness? And of these needs, which require the most attention in workplace culture change? Which are best fulfilled and when? The CAReS study seeks to address all of these questions and more. But, first, the study has focused on tool development to ensure that how the three psychological needs are measured is valid, reliable, and suitable to the engineering workplace context.

Methods

A survey was developed for the engineering CAReS study which contained demographic items, workplace information, several short answer/open-ended questions, and 171 Likert-scale items focused on competence, autonomy, and relatedness as well as barriers to workplace success (including sexual harassment and undermining) that have emerged from workplace literature over the past twenty years. Only items focused on competence, autonomy, and relatedness and related items (self-efficacy and belonging) were analyzed in this study with the goal of developing valid and reliable scales (and a shorter survey) for the next phase of engineering CAReS.

Participants and Procedures

Participants were recruited during 2022 for the first phase of engineering CAReS via e-mail and LinkedIn messaging by convenience sampling from the authors' professional networks and by snowballing via the contacts in those networks. Those eligible to complete the survey were individuals who (a) worked as engineers or computer scientists over the past 20 years or individuals who had worked closely with engineers or computer scientists over that same time period; and (b) worked for US companies or subsidiaries of non-US companies operating in the US. Individuals from academia and non-academia and from a broad range of engineering workplace settings (both corporate and government) completed the survey; 210 total responses were collected for the tool development phase.

Instruments

Survey items used in this study were either (a) taken directly from existing workplace scales; or (b) adapted from scales used in higher education. Those taken directly from existing workplace scales included satisfaction and frustration of relatedness, competence, and autonomy needs in the SDT literature [28][29]; an occupational belongingness scale [30]; and an occupational self-efficacy scale [31]. Items adapted from higher education scales included class level and university level belonging scales [32]. Survey items are listed in their entirety in the results section. To reduce manuscript length, those items are not repeated here.

Confirmatory Factor Analysis (CFA)

One-factor CFA was conducted on seven of the scales evaluated for use in the CAReS study: *occupational belongingness*, satisfaction and frustration of *autonomy needs*, satisfaction and frustration of *competence needs*, and satisfaction and frustration of *relatedness needs*. These seven scales contained items that were unchanged from previous studies where they had been validated in the workplace setting. In the tool development phase of CAReS, then, their validity needed only to be confirmed. Each standalone, one-factor CFA meets the range of minimum sample sizes established by Mundfrom et al. [33] for four variables/items per factor (N_{min} between 27 and 95 depending on communality) and for six variables/items per factor (N_{min} between 19 and 70 depending on communality). The total sample size for this study (N>200) is also consistent with a generally fair to good sample size as reported by Comrey and Lee in an earlier study [34].

Confirmatory factor analyses were conducted using R (version 4.0.2) and R studio (version 1.3) and the results evaluated using four goodness of fit indicators: chi-square (χ^2), the root mean

square error of approximation index (RMSEA), the comparative fit index (CFI), and the standardized root mean residual (SRMR). Chi-square tests whether the covariance matrix derived from a CFA model represents the covariance of the sample population (i.e., observed values). The null hypothesis for a chi-square test in CFA is that the model is a perfect fit to the sample population (i.e., the items make a perfect scale); therefore, rejection of the null hypothesis at a significant level (e.g., $p < 0.05$) is not desirable. The chi-square test is also non-parsimonious, meaning that the test does not seek out the smallest possible model for the best fit and that the larger the sample size, the more likely the test is to yield an erroneous, significant result [35]. In contrast, RMSEA accounts for sample size (N):

$$RMSEA = \sqrt{d/df} \; where \; d = (\chi^2 - df)/(N - 1)$$

where *df* are the degrees of freedom associated with the CFA. In general, RMSEA < 0.05 is considered a good fit, While RMSEA is not prone to bias at large sample sizes, it is biased against small *df* leading to erroneously high values that can be misinterpreted as poor model fit [36]. For most CFA, however, RMSEA values of < 0.05 are considered a good fit, between 0.05 and 0.08 an acceptable fit, between 0.08 and 0.1 a marginal fit, and greater than 0.1 a poor fit [37]. The two remaining goodness of fit indicators used in CFA associated with this study (CFI and SRMR) provide a means to confirm or potentially reject determinations of poor fit made by χ^2 tests or RMSEA. Unlike RMSEA which is an absolute fit index, meaning that it evaluates the hypothesized model (i.e., one factor CFA in the case of this study), the CFI is an incremental fit index, meaning that it compares the hypothesized model to the worst fit. A CFI of greater than 0.95 is generally considered a good model fit [36]. The SRMR is another absolute fit index which represents the difference between the correlations among observed data and the correlations generated by the model for that data. In effect, SRMR measures the average amount of discrepancy between observed and expected correlations among items in the CFA model. In general, an SRMR value between 0 and 0.08 is considered acceptable model fit [38].

Exploratory Factor Analysis (EFA)

For items that were adapted to the engineering workplace context and were no longer identical to items used in previously validated studies, exploratory factor analyses were used to generate valid constructs for the CAReS study. Items that fit this criterion included eleven total items borrowed from higher education contexts to measure belonging. An exploratory factor analysis was used to reduce the dimensionality of these items. This eleven variable/item, two-factor EFA meets the minimum sample size range established by Mundfrom et al. [33] for five variables/items per factor (N_{min} between 75 and 150 depending on communality) and for six variables/items per factor (N_{min} between 55 and 120 depending on communality). The total sample size (N>200) is also consistent with a fair to good sample size more generally reported by Comrey and Lee in an earlier study [34].

Prior to factor analysis, any one of a pair of items which were correlated at a level greater than 0.9 was discarded. Then, the Kaiser-Meyer-Olkin test [39] was used to measure how suitable the data were for factor analysis. Items that passed this test were then evaluated using Bartlett's test of sphericity [40] to determine if there was sufficient redundancy among the items to summarize them in a smaller number of factors (i.e., to reduce dimensionality of the data). Items that remained after this preliminary screening of the data were then used to produce a scree plot to

determine the number of factors that resulted in an eigenvalue of one and explained at least 50% of the variance in the data.

Using the number of factors determined from the scree plot, a factor analysis was conducted. Any items that had cross-loadings that exceeded 75% of the maximum loading were deleted [41]. Items that had uniqueness values greater than 0.6 were also deleted according to thresholds established by Osborne et al. [42]. Factor analysis was then repeated until no significant cross-loadings or uniqueness values remained. High cross-loadings suggest that an item is measuring more than one thing and is therefore not suitable for any single factor while uniqueness (equal to 1 minus communality) values higher than 0.6 suggest that the item/variable does not represent a common factor (or construct).

Results and Discussion

Eight confirmatory factor analyses and one exploratory factor analysis were conducted on the Phase 1 data of the Engineering CAReS study to validate the constructs in the engineering workplace environment. Among the confirmatory factor analyses, one construct (satisfaction of relatedness needs) failed to demonstrate satisfactory validity; one construct required deleting some items to achieve construct validity; and five achieved satisfactory validity with all of the initial items used to represent the construct. In the exploratory factor analysis of belonging items, two factors were determined to be adequate to describe the variance in the data: belonging at the organizational level and belonging at the workgroup level.

Confirmatory Factor Analysis of Relatedness Needs Scales: scales associated with satisfaction of relatedness needs and frustration of those needs were analyzed. Results of confirmatory factor analyses of both scales are summarized in Table 1. The goodness of fit indicators for the *satisfaction of relatedness* needs indicated a poor fit of the four items to this competence construct ($\chi^2 = 23.353$ ($p = 0.000$); RMSEA = 0.228). The sensitivity of χ^2 statistics to sample size and the diminished suitability of RMSEA for judging models at small sample sizes [36] alongside excellent CFI (0.972) and acceptable SRMR (0.036) could be considered sufficient reason to retain the *satisfaction of relatedness needs* as a subscale for relatedness in this study. However, since multiple belonging/relatedness scales were assessed in this study, only the best fit scales were retained for the CAReS study. Therefore, the *satisfaction of relatedness needs* subscale was eliminated. Unlike the satisfaction of relatedness needs subscale, the goodness of fit indicators for the *frustration of relatedness needs* were within acceptable range ($\chi^2 = 1.828$ ($p = 0.401$); RMSEA = 0.000; CFI = 1.000; SRMR = 0.005), thereby confirming the construct validity of this scale and justifying its use in the CAReS study.

Several alternatives to the satisfaction of relatedness needs were considered. The original occupational belongingness scale developed and validated by Jena and Pradhan [30] contained twelve items. Four items had correlations among their residuals that exceeded 0.1, indicating that they were more correlated than they should be and were essentially saying the same thing. These items were:

- I feel that my values and beliefs are a good fit to this organization
- Fairness is maintained while executing rules and policies in my organization
- My career goals are considered by my organization
- Accomplishments at work are adequately rewarded in my organization

Table 1: Confirmatory Factor Analysis for Relatedness Scales

Item	Loading	Goodness of Fit Indicators
Satisfaction of Relatedness Needs		
I feel that the people I care about at work also care about me	0.841	degrees of freedom (df) = 2 $\chi^2 = 23.53$ ($p = 0.000$) RMSEA = 0.228 confidence interval: 0.155 – 0.310 Comparative Fit Index (CFI) = 0.991 Standardized Root Mean Residual SRMR = 0.030
I feel connected with people who care for me at work, and for whom I care about at work	0.849	
At work, I feel close and connected with other people who are important to me	0.899	
I experience a warm feeling with the people I spend time with at work	0.807	
Frustration of Relatedness Needs		
I feel excluded from the group I want to belong to at work	0.736	degrees of freedom (df) = 2 $\chi^2 = 0.179$ ($p = 0.914$) RMSEA = 0.000 confidence interval: 0.000 – 0.057 Comparative Fit Index (CFI) = 1.000 Standardized Root Mean Residual SRMR = 0.005
I feel that people who are important to me at work are cold and distant towards me	0.833	
I have the impression that people I spend time with at work dislike me	0.793	
I feel the relationships I have at work are just superficial	0.612	

An additional two items indicated factor loadings less than 0.6 and were removed to reduce the length of the survey without loss of fit and validity:

- I refer to "we/us" rather than "they/them" when I refer to my organization to outsiders
- In my workgroup, I have a lot in common with my co-workers

After reducing the occupational belongingness scale to six items by removing the preceding items, the remaining scale demonstrated an acceptable fit (RMSEA = 0.058) with CFI (0.989) and SRMR (0.027) well within the acceptable range of values for a good fit. Therefore, the six-item occupational belonging scale was retained for the CAReS study (Table 2).

Table 2: Confirmatory Factor Analysis for Occupational Belonging Scale

Item	Loading	Goodness of Fit Indicators
Occupational Belonging		
I am able to work in this organization without sacrificing my principles	0.626	degrees of freedom (df) = 9 $\chi^2 = 16.203$ ($p = 0.063$) RMSEA = 0.058 confidence interval: 0.000 – 0.105 Comparative Fit Index (CFI) = 0.989 Standardized Root Mean Residual
I generally carry more positive emotions than negative ones about my job	0.750	
Being a part of this organization inspires me to do more than what is expected	0.666	
My personal needs are well met by my organization	0.854	

Whenever I have any personal or professional issues, my organization extends necessary help and support	0.803	SRMR = 0.027
My organization tries to make my job as exciting and promising as possible	0.672	

Because the main focus of the CAReS study is belonging, additional belonging items from higher education studies were adapted to the workplace and considered during survey development. Because all eleven items were not previously validated in the workplace context, exploratory factor analysis was conducted to evaluate the suitability of these items for workplace studies. Using the screening steps identified in the Methods section, no items were deleted from consideration, resulting in six items that cleanly loaded onto the one factor and five items onto the second factor in a two-factor analysis (Table 3). These two factors explained 66% of the variance in the data and were retained as scales labelled *organizational belonging* and *workgroup belonging.*

Table 3: Exploratory Factor Analysis for Additional Belonging Scales

	Loadings (>0.3)	
Item	Factor 1	Factor 2
Belonging at the Organizational Level		
I really enjoy working here	0.89	
I feel like I really belong at this organization	0.65	
I wish I had taken a job at another organization instead of this one	-0.90	
I wish I worked at a job in another organization	-1.01	
I feel that there is a real sense of community in this organization	0.51	
I feel like there is a strong feeling of togetherness in this organization	0.49	
Belonging at the Workgroup Level		
I feel that I am supported by my immediate workgroup		0.62
I feel that I am part of my immediate workgroup		0.79
I feel that I am accepted by my coworkers		1.05
I feel comfortable in my immediate workgroup		0.97
People in this organization are friendly to me		0.50

Confirmatory Factor Analysis of Competence Needs Scales: Results of confirmatory factor analyses for the two competence subscales are shown in Table 4. The goodness of fit indicators for the *satisfaction of competence needs* were within acceptable range ($\chi^2 = 2.548$ with df = 2 and $p = 0.714$; RMSEA = 0.042; CFI = 0.999; SRMR = 0.008), thereby confirming the construct validity of this scale. The *frustration of competence needs*, however, indicated a poor fit of the four items to this competence construct ($\chi^2 = 17.211$ with df = 2 and $p = 0.000$; RMSEA = 0.189; CFI = 0.972; SRMR = 0.027). However, the χ^2 statistic is highly sensitive to sample size so much so that it has been suggested that for a sample size greater than 200, chi square is highly likely to produce a significant result ($p < 0.05$) even for a CFA model that is a good fit to the data [33]. Furthermore, for small degrees of freedom, Kenny et al. indicated that RMSEA is not

meaningful [34] and the comparative fit index (CFI) and standardizes root mean square residual (SRMR) should be used instead to judge model fit. Both CFI (greater than 0.95) and SRMR (less than 0.08) were well within acceptable limits for the one factor frustration of competence needs model. Therefore, the *frustration of competence* needs construct was retained with caution for the CAReS study.

Table 4: Confirmatory Factor Analysis for Competence Subscales

Item	Loading	Goodness of Fit Indicators
Satisfaction of Competences Needs		
I feel confident that I can do things well on my job	0.891	degrees of freedom (df) = 2 $\chi^2 = 2.548$ ($p = 0.714$) RMSEA = 0.042 confidence interval: 0.000 – 0.160 Comparative Fit Index (CFI) = 0.999 Standardized Root Mean Residual SRMR = 0.008
At work, I feel capable at what I do	0.918	
When I am at work, I feel competent to achieve my goals	0.916	
In my job, I feel I can successfully complete difficult tasks	0.822	
Frustration of Competence Needs		
When I am at work, I have serious doubts about whether I can do things well	0.736	degrees of freedom (df) = 2 $\chi^2 = 17.211$; df = 2 ($p = 0.000$) RMSEA = 0.189 confidence interval: 0.113 – 0.189 Comparative Fit Index (CFI) = 0.972 Standardized Root Mean Residual SRMR = 0.027
I feel disappointed with my performance in my job	0.833	
I feel insecure about my abilities in my job	0.793	
When I am working, I feel like a failure because of the mistakes I make	0.612	

Confirmatory Factor Analysis of Self-Efficacy Scale: Results of confirmatory factor analyses for the single self-efficacy scale used in this study are shown in Table 5.

Table 5: Confirmatory Factor Analysis for Self-Efficacy

Item	Loading	Goodness of Fit Indicators
Occupational Self Efficacy		
I can remain calm when facing difficulties in my job because I can rely on my abilities	0.804	Degrees of freedom (df) = 9 $\chi^2 = 14.717$ ($p = 0.099$) RMSEA = 0.059 confidence interval: 0.000 - 0.126 Comparative Fit Index (CFI) = 0.991 Standardized Root Mean Residual SRMR = 0.032
When I am confronted with a problem in my job, I can usually find several solutions	0.709	
Whatever comes my way in my job, I can usually handle it	0.945	
My past experiences in my job have prepared me well for my occupational future	0.555	
I meet the goals that I set for myself in my job	0.700	
I feel prepared for most of the demands in my job	0.824	

All of the goodness of fit indicators for *occupational self-efficacy* were within acceptable range (df = 9 and χ^2 = 14.717 with p = 0.099; RMSEA = 0.059; CFI = 0.991; SRMR = 0.032), thereby confirming the construct validity of this scale. Competence and self-efficacy are similar constructs; in the scales used in this study, the two constructs are largely distinguished by how individuals feel about their abilities (competence) compared to what they judge they are actually able to accomplish (self-efficacy) [43]. Competence is central to self-determination theory (SDT) [44] while self-efficacy is a key component of social cognitive theory (SCT) [43]. Research has shown that while the two constructs are similar, they remain empirically distinct from one another and may independently contribute to persistence in behavior [46]. Thus, both competence and self-efficacy constructs were retained in this study.

Confirmatory Factor Analysis of Autonomy Needs Scales: Autonomy is the last of the three basic psychological needs associated with SDT that was analyzed in the engineering workplace context. Results of confirmatory factor analysis for both the satisfaction and frustration of autonomy needs are shown in Table 6. The goodness of fit indicators for the *satisfaction of autonomy needs* were within acceptable range (χ^2 = 1.828 (p = 0.401); RMSEA = 0.000; CFI = 1.000; SRMR = 0.011), thereby confirming the construct validity of this scale. Factor loadings for two items on this scale were very good (between 0.63 and 0.71) and two were excellent (greater than 0.71) according to the stringent cut-offs recommended by Tabachnik and Fidell [47]. Thus, the *satisfaction of autonomy needs* scale was retained without reservation for this study.

Table 6: Confirmatory Factor Analysis for Autonomy Subscales

Item	Loading	Goodness of Fit Indicators
Satisfaction of Autonomy Needs		
At work, I feel a sense of choice and freedom in the things I undertake	0.656	degrees of freedom (df) = 2 χ^2 = 1.828 (p = 0.401) RMSEA = 0.000 confidence interval: 0.000 - 0.118 Comparative Fit Index (CFI) = 1.000 Standardized Root Mean Residual SRMR = 0.011
I feel that my decisions on my job reflect what I really want	0.820	
I feel my choices on my job express who I really am	0.820	
I feel I have been doing what really interests me in my job	0.670	
Frustration of Autonomy Needs		
Most of the things I do on my job feel like "I have to"	0.748	degrees of freedom (df) = 2 χ^2 = 11.756 (p = 0.003) RMSEA = 0.142 confidence interval: 0.000 – 0.177 Comparative Fit Index (CFI) = 0.972 Standardized Root Mean Residual SRMR = 0.036
I feel forced to do many things on my job I wouldn't choose to do	0.715	
I feel pressured to do too many things on my job	0.587	
My daily activities at work feel like a chain of obligations	0.872	

In contrast, the *frustration of autonomy* needs indicated a poor fit of the four items to this model (χ^2 = 11.756 (p = 0.000); RMSEA = 0.142). Similar to the CFA model fit for the frustration of competence needs, the sensitivity of χ^2 statistics to sample size and the diminished suitability of

RMSEA for judging model at small sample sizes [34] alongside excellent CFI (0.972) and acceptable SRMR (0.036) were considered sufficient reason to retain the *frustration of autonomy needs* as a subscale for autonomy in this study. Of the factor loadings for the four items on this scale, three were excellent [47] and one item indicated only good loading (0.587); for sample sizes of 200 or greater, however, 0.587 is considered a significant loading, making it acceptable for this scale [48, p. 112].

Descriptive statistics were computed for all nine measures (Table 7). The kurtosis and skewness of all measures fell within the acceptable range of a normal distribution between -7 and +7 and -2 and +2 respectively for all variables [49]. The internal reliability of all measures was calculated using Cronbach's alpha levels. All reliabilities were greater than 0.7 [50] and were therefore suitable for use in future surveys.

Table 7: Descriptive Statistics for CAReS Constructs

Construct	Mean	Median	SD	Skew	Kurtosis
Relatedness					
Frustration of Relatedness Needs	1.97	2.00	0.68	0.99	1.71
Occupational Belonging	3.43	3.50	0.83	-0.37	-0.24
Organizational Belonging	3.07	3.00	0.41	0.18	0.89
Workgroup Belonging	3.96	4.00	0.80	-0.78	0.80
Competence					
Satisfaction of Competence Needs	3.97	4.00	0.73	-0.71	0.66
Frustration of Competence Needs	2.16	2.00	0.90	0.84	0.34
Occupational Self-Efficacy	3.91	4.00	0.61	-0.61	1.05
Autonomy					
Satisfaction of Autonomy Needs	3.53	3.50	0.83	-0.38	-0.45
Frustration of Autonomy Needs	2.59	2.50	0.84	0.35	-0.48

Limitations

The present study had limited sample size ($N = 210$) which constrained how many items could be analyzed with a single exploratory factor analysis. However, for those items that were adapted for studying the workplace, all eleven items loaded cleanly onto two factors, which reduces the possibility of sample-size induced errors. Further, confirmatory factor analyses indicated potentially poor fit for two scales (*frustration of competence needs* and *frustration of autonomy needs*); thus, these scales should be used with caution in the next phase of the CAReS study and may end up being thrown out altogether due to persistently poor fit. One scale (*satisfaction of relatedness needs*) demonstrated poor fit and had to be removed from the survey. However, two of the three belonging scales that will be retained for the next phase of study are likely an adequate substitute for satisfaction of relatedness needs.

Conclusions

The tool development phase of the Engineering CAReS study used confirmatory and exploratory factor analyses of over 200 responses from working engineers to identify and validate nine scales suitable for measuring the satisfaction and frustration of autonomy, competence, and relatedness needs. Of those nine scales, two (occupational and organizational belonging) are sufficiently redundant to eliminate one. The result is eight scales suitable for integration into a much shorter survey for use in nationwide distribution of the Engineering CAReS survey. Future work will report the results of factor analyses of additional measures used in this study (e.g., sexual harassment and self-efficacy scales/measures). Future work will also recruit a larger (N = 3,000-4,000) sample of respondents to complete the shorter, refined survey in order to gain an understanding of the degree to which the basic psychological needs are satisfied or frustrated across geographic regions, genders, races, and other individual and workplace demographic factors.

References

[1] S.A. Hewlett, C.B. Luce, L.J. Servon, L. Sherbin, P. Shiller, E. Sosnovich, and K. Sumberg. "The Athena factor: Reversing the brain drain in science, engineering, and technology." *Harvard Business Review Research Report*, vol. 10094, pp. 1-100, 2008.

[2] J S.A. Hewlett, L. Sherbin, F. Dieudonne,, C. Fargnoli, and C. Fredman, C. *Athena 2.0: Accelerating female talent in science, engineering, and Technology*. Center for Talent Innovation, 2014. [Online]. http://www.talentinnovation.org/publication.cfm?publication=1420

[3] J. Williams, S. Li, R. Rincon, and P. Finn, "Climate Control: Gender and Racial Bias in Engineering?," *SSRN Electronic Journal*, 2016, doi: 10.2139/ssrn.4014946.

[4] R. Yonemura and D. Wilson, "Exploring Barriers in the Engineering Workplace: Hostile, Unsupportive, and Otherwise Chilly Conditions," in *ASEE Annual Conference & Exposition Proceedings*, *New Orleans, Louisiana, Jun. 26-29, 2016,* doi: 10.18260/p.26843.

[5] E. L. Deci and R. M. Ryan, "Autonomy and Need Satisfaction in Close Relationships: Relationships Motivation Theory," in *Human Motivation and Interpersonal Relationships*, N. Weinstein, N., Ed. Berlin, Germany: Springer, Dordrecht, pp. 53-73, https://doi.org/10.1007/978-94-017-8542-6_3 pp. 53–73, 2014, doi: 10.1007/978-94-017-8542-6_3.

[6] E.L. Deci and R.M. Ryan, Facilitating optimal motivation and psychological well-being across life's domains." *Canadian psychology/Psychologie canadienne*, vol. 9, no. 1, pp. 14-23, 2008, https://doi.org/10.1037/0708-5591.49.1.14

[7] J.P. Meyer and R.R. Maltin. "Employee commitment and well-being: A critical review, theoretical framework and research agenda." *Journal of vocational behavior*, vol. 77, no. 2, pp. 323-337, 2010.

[8] M. Vansteenkiste and R.M. Ryan. "On psychological growth and vulnerability: basic psychological need satisfaction and need frustration as a unifying principle." *Journal of psychotherapy integration*, vol. 23, no. 3, pp. 263–280, Sep. 2013, doi: 10.1037/a0032359.

[9] L. Legault, “The need for competence,” in *Encyclopedia of Personality and Individual Differences*, V. Zeigler-Hill and T.K. Shackelford, Eds. Boston, MA: Springer, 2017, pp. 978-983.

[10] R.F. Baumeister and M.R. Leary. "The need to belong: Desire for interpersonal attachments as a fundamental human motivation." *Interpersonal development*, pp. 57–89, Nov. 2017, doi: 10.4324/9781351153683-3.

[11] M. S. Hagger, S. J. Hardcastle, A. Chater, C. Mallett, S. Pal, and N. L. D. Chatzisarantis, “Autonomous and controlled motivational regulations for multiple health-related behaviors: between- and within-participants analyses,” *Health Psychology and Behavioral Medicine*, vol. 2, no. 1, pp. 565–601, Jan. 2014, doi: 10.1080/21642850.2014.912945.

[12] N. Ntoumanis, J. YY Ng, A. Prestwich, E. Quested, J.E. Hancox, C. Thøgersen-Ntoumani, E.L. Deci, R.M. Ryan, C.Lonsdale, and G.C. Williams. “A meta-analysis of self-determination theory-informed intervention studies in the health domain: effects on motivation, health behavior, physical, and psychological health,” *Health Psychology Review*, vol. 15, no. 2, pp. 214–244, Feb. 2020, doi: 10.1080/17437199.2020.1718529.

[13] R. M. Ryan and E. L. Deci, Eds., *Self-Determination Theory: Basic Psychological Needs in Motivation, Development, and Wellness*, New York City: The Guilford Press, 2017, doi: 10.1521/978.14625/28806.

[14] A. H. Olafsen, E. L. Deci, and H. Halvari, “Basic psychological needs and work motivation: A longitudinal test of directionality,” *Motivation and Emotion*, vol. 42, no. 2, pp. 178–189, Nov. 2017, doi: 10.1007/s11031-017-9646-2.

[15] T. Kasser, J. Davey, and R. M. Ryan, “Motivation and employee-supervisor discrepancies in a psychiatric vocational rehabilitation setting.,” *Rehabilitation Psychology*, vol. 37, no. 3, pp. 175–188, 1992, doi: 10.1037/h0079104.

[16] B. C. Ilardi, D. Leone, T. Kasser, and R. M. Ryan, “Employee and Supervisor Ratings of Motivation: Main Effects and Discrepancies Associated with Job Satisfaction and Adjustment in a Factory Setting1,” *Journal of Applied Social Psychology*, vol. 23, no. 21, pp. 1789–1805, Nov. 1993, doi: 10.1111/j.1559-1816.1993.tb01066.x.

[17] M. F. Lynch, R. W. Plant, and R. M. Ryan, “Psychological Needs and Threat to Safety: Implications for Staff and Patients in a Psychiatric Hospital for Youth.,” *Professional Psychology: Research and Practice*, vol. 36, no. 4, pp. 415–425, Aug. 2005, doi: 10.1037/0735-7028.36.4.415.

[18] P. P. Baard, E. L. Deci, and R. M. Ryan, “Intrinsic Need Satisfaction: A Motivational Basis of Performance and Weil-Being in Two Work Settings1,” *Journal of Applied Social Psychology*, vol. 34, no. 10, pp. 2045–2068, Oct. 2004, doi: 10.1111/j.1559-1816.2004.tb02690.x.

[19] E. L. Deci, R. M. Ryan, M. Gagné, D. R. Leone, J. Usunov, and B. P. Kornazheva, “Need Satisfaction, Motivation, and Well-Being in the Work Organizations of a Former Eastern Bloc Country: A Cross-Cultural Study of Self-Determination,”

Personality and Social Psychology Bulletin, vol. 27, no. 8, pp. 930–942, Aug. 2001, doi: 10.1177/0146167201278002.

[20] M. Gagné, "The role of autonomy support and autonomy orientation in prosocial behavior engagement." *Motivation and Emotion*, vol. 27, pp. 199-223, 2003.

[21] A. Gil-Flórez, S. Llorens, H. Acosta-Antognoni, and M. Salanova. "Basic Psychological Needs at Work: Their Relationship with Psychological Well-Being and Healthy Organisational Outcomes with a Gender Perspective." *International Journal of Environmental Research and Public Health*, vol. 19, no. 5, 3103, 2022.

[22] G.C. Williams, H. Hallgeir, C.P. Niemiec, O. Sørebø, A.H. Olafsen, and C. Westbye. "Managerial support for basic psychological needs, somatic symptom burden and work-related correlates: A self-determination theory perspective." *Work & Stress*, vol. 28, no. 4, pp. 404-419, 2014.

[23] M. Vansteenkiste, B. Neyrinck, C.P. Niemiec, B. Soenens, H. De Witte, and A. Van den Broeck. "On the relations among work value orientations, psychological need satisfaction and job outcomes: A self-determination theory approach." *Journal of occupational and organizational psychology*, vol. 80, no. 2, pp. 251-277, 2007.

[24] A.D. Van den Broeck, L. Ferris, C.H. Chang, and C.C. Rosen. "A review of self-determination theory's basic psychological needs at work." *Journal of Management*, vol. 42, no. 5, pp. 1195-1229, 2016.

[25] N.R. Magson, Rhonda G. Craven, Richard M. Ryan, Anthony Dillon, Janet Mooney, Fabri Blacklock, Alexander S. Yeung, Munirah S. Kadir, and Alicia Franklin. "A Cross-Cultural Investigation of Basic Psychological Need Satisfaction at Work in an Indigenous and Non-Indigenous Australian Sample Across Occupation Types." *Journal of Cross-Cultural Psychology*, vol. 53, no. 2, pp. 213-238, 2022.

[26] Coxen, Lynelle, Leoni van der Vaart, Anja Van den Broeck, and Sebastiaan Rothmann. "Basic psychological needs in the work context: a systematic literature review of diary studies." *Frontiers in Psychology*, vol. 12, 698526, 2021, doi: 10.3389/fpsyg.2021.698526

[27] N. A. Fouad, W.-H. Chang, M. Wan, and R. Singh, "Women's Reasons for Leaving the Engineering Field," *Frontiers in Psychology*, vol. 8, Jun. 2017, doi: 10.3389/fpsyg.2017.00875.

[28] P. P. Schultz, R. M. Ryan, C. P. Niemiec, N. Legate, and G. C. Williams, "Mindfulness, Work Climate, and Psychological Need Satisfaction in Employee Well-being," *Mindfulness*, vol. 6, no. 5, pp. 971–985, Sep. 2014, doi: 10.1007/s12671-014-0338-7.

[29] J. Van der Kaap-Deeder, B. Soenens, R.M. Ryan, and M. Vansteenkiste, *Manual of the Basic Psychological Need Satisfaction and Frustration Scale (BPNSFS)*. Belgium: Ghent University, 2020.

[30] L. K. Jena and S. Pradhan, "Conceptualizing and validating workplace belongingness scale," *Journal of Organizational Change Management*, vol. 31, no. 2, pp. 451–462, Apr. 2018, doi: 10.1108/jocm-05-2017-0195.

[31] T. Rigotti, B. Schyns, and G. Mohr, “A Short Version of the Occupational Self-Efficacy Scale: Structural and Construct Validity Across Five Countries,” *Journal of Career Assessment*, vol. 16, no. 2, pp. 238–255, May 2008, doi: 10.1177/1069072707305763.

[32] D. Wilson et al., “Belonging and Academic Engagement Among Undergraduate STEM Students: A Multi-institutional Study,” *Research in Higher Education*, vol. 56, no. 7, pp. 750–776, Mar. 2015, doi: 10.1007/s11162-015-9367-x.

[33] D.J. Mundfrom, D.G. Shaw, and T.L. Ke, "Minimum sample size recommendations for conducting factor analyses." *International journal of testing* vol. 5, no. 2, pp. 159-168, 2005. https://doi.org/10.1207/s15327574ijt0502_4

[34] A.L. Comrey and H.B. Lee, *A first course in factor analysis*. Hillsdale, NJ: Lawrence Erlbaum Associates, 1992.

[35] M. Alavi, D. C. Visentin, D. K. Thapa, G. E. Hunt, R. Watson, and M. Cleary, “Chi-square for model fit in confirmatory factor analysis,” *Journal of Advanced Nursing*, vol. 76, no. 9, pp. 2209–2211, May 2020, doi: 10.1111/jan.14399.

[36] D. A. Kenny, B. Kaniskan, and D. B. McCoach, “The Performance of RMSEA in Models With Small Degrees of Freedom,” *Sociological Methods & Research*, vol. 44, no. 3, pp. 486–507, Jul. 2014, doi: 10.1177/0049124114543236.

[37] L. R. Fabrigar, D. T. Wegener, R. C. MacCallum, and E. J. Strahan, “Evaluating the use of exploratory factor analysis in psychological research.,” *Psychological Methods*, vol. 4, no. 3, pp. 272–299, Sep. 1999, doi: 10.1037/1082-989x.4.3.272.

[38] L. Hu and P. M. Bentler, “Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives,” *Structural Equation Modeling: A Multidisciplinary Journal*, vol. 6, no. 1, pp. 1–55, Jan. 1999, doi: 10.1080/10705519909540118.

[39] H. F. Kaiser and J. Rice, “Little Jiffy, Mark Iv,” *Educational and Psychological Measurement*, vol. 34, no. 1, pp. 111–117, Apr. 1974, doi: 10.1177/001316447403400115.

[40] M. S. Bartlett, “Properties of Sufficiency and Statistical Tests,” *Proc. R. Soc. Lond.*, vol. 160, pp. 268-282, 1937, http://doi.org/10.1098/rspa.1937.0109

[41] Samuels, Peter. "Advice on exploratory factor analysis,” 2017. [Online]. Available: https://www.open-access.bcu.ac.uk/6076/1/__staff_shares_storage%20500mb_Library_ID112668_Stats%20Advisory_New%20Statistics%20Workshops_18ExploratoryFactorAnalysis_ExploratoryFactorAnalysis4.pdf

[42] J.W. Osborne, A.B. Costello, and J.T. Kellow. “Best Practices in Exploratory Factor Analysis,” *Best Practices in Quantitative Methods*. J.W. Osborne, Ed. Los Angeles, CA: Sage Publications, 2008.

[43] J. Kremer, M. Aidan, G.W. Moran, and C. Craig. *Key concepts in sport psychology*. Los Angeles, CA: Sage Publications, 2011.

[44] E.L. Deci and R.M. Ryan. "Self-determination research: Reflections and future directions," in *Handbook of Self-determination Research*, E. L. Deci & R. M. Ryan, Eds. Rochester, NY: University of Rochester Press, pp. 431–441, 2002.

[45] Bandura, Albert. "The explanatory and predictive scope of self-efficacy theory," *Journal of social and clinical psychology,* vol. 4, no. 3, pp. 359-373, 1986.

[46] W. M. Rodgers, D. Markland, A.-M. Selzler, T. C. Murray, and P. M. Wilson, "Distinguishing Perceived Competence and Self-Efficacy: An Example From Exercise," *Research Quarterly for Exercise and Sport*, vol. 85, no. 4, pp. 527–539, Oct. 2014, doi: 10.1080/02701367.2014.961050.

[47] B.G. Tabachnick and L.S. Fidell. *Using multivariate statistics* (5th ed). Boston, MA: Allyn and Bacon, 2007.

[48] J.F. Hair, "Multivariate data analysis: An overview," in *International Encyclopedia of Statistical Science*, M. Lovric, Ed. Berlin, Germany: Springer, 2011, pp. 904-907.

[49] D. George and P. Mallery. *IBM SPSS statistics 26 step by step: A simple guide and reference*. Oxfordshire, England: Routledge, 2019.

[50] A. Field, J. Miles, and Z. Field. *Discovering statistics using R.* Los Angeles, CA: Sage Publications, 2012.