Insights from industry: a quantitative analysis of engineers' perceptions of empathy and care within their practice

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Abstract:

This study focuses on two seldom-investigated skills or dispositions aligned with engineering habits of mind – empathy and care. In order to conduct quantitative research, we designed, explored the underlying structure of, validated, and tested the reliability of the Empathy and Care Questionnaire (ECQ), a new psychometric instrument. In the second part, we used the ECQ to explore the perceptions of empathy and care of alumni/ae of an internationally ranked US institution, along with how perceptions differed by work experience and gender. Results show that participants perceived empathy and care to be important in multiple respects, most notably in relational aspects of engineering practice. Engineers with more engineering experience were more likely to perceive empathy and care as existing in engineering practice and as important to their work. While these phenomena are sometimes depicted as feminine qualities, we found no gender differences among our respondents.

Keywords: empathy | care | engineering practice | engineering education | survey design | psychometrics

Article:

Introduction

This study continues the discussion on what skills or dispositions engineers should possess (National Academy of Engineering [NAE] 2004), specifically focusing on two attributes that are core to NAE's (2009) 'habits of mind', empathy and care. Smith, Johson, and Johnson (1981) suggested more than 30 years ago that engineering learning goals fall into three related categories: technological, interpersonal, and social-technical. Today, the drive to incorporate competencies beyond technological into engineering education persists. Adams and Felder (2008) suggested this is because engineers are required to 'develop innovative products, exercise new and unfamiliar technical and profession skills, and function in an increasingly global environment' (239). Similarly, Niewoehner and Steidle (2009) suggested professional engineers must develop certain intellectual virtues to thrive in this dynamic professional environment. One of these they called intellectual empathy, which they described as follows:

> Intellectual empathy is awareness of the need to actively entertain views that differ from our own, especially those with which we strongly disagree. It entails accurately reconstructing others' viewpoints and to self-consciously reason from premises, assumptions, and ideas other than our own. (11)

Similarly, standards of care have become a prominent focus in scholarly engineering literature, especially in the domain of engineering ethics (Haws 2001; Kardon 2005, 2006; Pantazidou and Nair 1999). For example, the American Society of Civil Engineers' (ASCE Steering Committee 2006) vision is that by 2025 all civil engineers will lead 'by formulating and articulating environmental, infrastructure, and other improvements and build consensus by practicing inclusiveness, empathy, compassion, persuasiveness, patience, and critical thinking' (11).

Beyond engineering, empathy has been postulated as the essential ingredient for human subsistence (Rifkin 2009; de Waal 2009). Hoffman (2000) situated empathy within the core of his theory of moral development, as he posited that empathy is 'the spark of human concern for others, the glue that makes social life possible' (3). Further, recent studies in cognitive neuroscience, such as the discovery of mirror neurons, have led scientists to suggest empathy is innate to nearly all of humanity (Iacoboni 2009; Iacoboni and Dapretto 2006) and that a lack of empathy, as evident via the dysfunction of the mirror neuron system, is directly related to autism (Iacoboni and Dapretto 2006) and is highly correlated with psychopathy (Baron-Cohen 2011).

This study explores the extent to which empathy and care already exist within engineering by synthesising how a diverse range of practicing engineers (as evidenced by their disciplines and experiential levels) perceived empathy and care to be important within their practice. While disciplines outside of engineering have integrated empathy and care into their standards and curriculum extensively, engineering as a discipline has only recently followed suit. Conversely, while fields outside of engineering have been developing their own discipline-specific emergent understanding of empathy for decades, and while a wide debate and range of perceptions regarding the utility of empathy within those fields exist (Batson 2009; Kunyk and Olson 2001), the discipline-specific understanding and debate in engineering are still in their infancy. Nonetheless, promoting empathy and care within engineering practice may have many benefits, such as heightening the individual engineer's ability to anticipate and resolve interpersonal problems (Baron-Cohen 2011), understand the needs of users (Hey et al. 2007; Leonard and Rayport 1997), become intrinsically motivated to act altruistically (Batson, Ahmad, and Lishner 2011; Eisenberg and Miller 1987), or make ethical decisions (Hoffman 2000; Oxley 2011; Pantazidou and Nair 1999; Vallero 2008).

Due to an emergent focus on these phenomena within engineering (Walther, Miller and Sochacka in press), there is a need for an exploration of where their integration might be most beneficial for the practice of engineering. A concerted and quantitative focus on practicing engineers' perceived importance of empathy and care within engineering is vital to understanding how important these phenomena are for understanding stakeholders, designing user-centric solutions, communicating effectively, making ethical and sustainable decisions, or improving relationships with clients and team members. Further, it can highlight any discrepancies between the existence of empathy and care within engineering practice relative to these phenomena's perceived importance, as well as how these perceptions vary across experiential groups and by gender.

Literature review

Few articles within engineering clearly conceptualise empathy or care when employing these terms, despite their inherent complexity (Batson 2009). Therefore, in the following section, we explore conceptualisations of these phenomena in literature outside of engineering. In the subsequent section, we describe considerations or contexts for situating empathy within engineering. Lastly, we describe this study's conceptual framework that frames these phenomena for the purposes of this investigation.

Conceptualisations of empathy and care outside of engineering

Throughout scholarly literature, empathy is often divided into one, two, or even three core components: (a) knowing what another is feeling, (b) feeling what another is feeling, or (c) responding to another (Levenson and Ruef 1992). Wispé (1986) suggested empathy was best understood only as a way of knowing, as opposed to sympathy which involves feeling. Lawrence and others (2006) distinguished between cognitive and affective empathy, where the cognitive aspect involves 'understanding and predicting some else's mental state' and the affective aspect involves 'experiencing an emotion as the result of some else's mental state' (1173).

Oxley (2011) argued that the affective dimension was essential to 'true' empathy, as it enables a congruent emotion to that of the other. In other words, empathy's affective component may be required if empathy's cognitive functions are to be accurate representations of another's state of being (de Waal 2009). Contrariwise, Hoffman (2000) defined empathy as an 'affective response more appropriate to another's situation than one's own' (4) but emphasised that this response can also be primed by cognitive empathy, such as role-taking and mediated association.

Empathy also involves reasoning or feeling between self- and other-oriented perspectives (Davis 1996), but when individuals blur the self-other boundary (e.g. they feel as if the other is identical to themselves), their empathic accuracy declines (Decety and Jackson 2004; Lawrence et al. 2006). Hence, empathic perspective taking requires the individual to interpret the other's perspective through his or her own lens. The accuracy of this lens will be situation specific and will depend on a number of factors, such as cultural similarities, differences, one's relationship with the other, and other contextual factors (Hoffman 2000; Ickes 1997).

Care is a similarly complex phenomenon with numerous and highly variable language uses. Mayeroff (1971) defined caring as helping another grow in their own unique way. Pantazidou and Nair (1999) defined care as 'responding to another out of something more than pure interest' and as an implied response that 'will lead to action' (207). Hoffman (2000) depicted care as a guiding moral principle that requires the decision-maker to 'always consider others' (225). In this same respect, Batson, Ahmad, and Lishner (2011) linked care (and empathy) directly to altruistic action (e.g. action intended to help the other with no resulting benefit to the actor).

There is no consensus on how exactly empathy and care are related, even in domains outside of engineering. Some scholars postulate that empathy leads to caring (Batson, Ahmad, and Lishner 2011) whereas others recognise caring as a component of empathy (Fernández-Olano, Montoya-Fernández, and Salinas-Sánchez 2008; Kunyk and Olson 2001). For example, within nursing literature, empathy has been depicted as care, where care involves concern for the outcome of an intervention (Kunyk and Olson 2001). Similarly, Newman and Newman (2012) suggested caring builds on emotions aroused by empathy. Lastly, Sutherland (1993) depicted empathy as a process which starts with cognition, which leads to affect, which culminates in a behavioural response (e.g. caring helping behaviour).

In the context of moral development, Gilligan (1982) indicated that ‘sensitivity to the needs of others and the assumptions of responsibility for taking care’ can lead one to ‘include in their judgment other points of view’ (16). Oxley (2011) flipped this notion, suggesting that empathy can make the salience of another’s situation internally meaningful. Taking these ideas together, Hoffman (2000) postulated, ‘Empathy and caring principles are thus independent, mutually supportive, hence congruent dispositions to help others’ (225). Therefore, taken together, empathy and care would include the motivational force to understand another’s need and to help that other in some manner.

Situating empathy and care within engineering

Prior to 2011, the explicit usage of empathy and care within engineering literature was rare. For example, Strobel et al. (2011) found only 22 peer-reviewed articles published after 1980 within engineering literature that explicitly used the term empathy in some form. The authors grouped the found literature into (a) engineering education, (b) engineering management, (c) engineering ethics, and (d) engineering professional development. A closer analysis indicated that empathy was only the core focus of one of these articles (Vallero and Vesilind 2006) and was a subsidiary point of emphasis in all others, as evident by its limited usage.

Likewise, Strobel et al. (2011) found that care/caring was only a focal point of 22 articles within engineering literature, compared to thousands of articles focusing on care outside of engineering. In this engineering literature, care was depicted as (a) core to designing products that satisfy users’ needs (Ermer and Vanderleest 2002), (b) a guiding ethical principle for problem solving (Pantazidou and Nair 1999), (c) a key component of environmental education (Hyde and Karney 2001), (d) a professional duty or obligation for engineers (Kardon 2005), or (e) as an approach to bring or retain women within engineering (Starobin et al. 2010).

In the past few years, explicit usage of empathy and care within engineering literature has become more common, as evident by searching the American Society for Engineering Education’s (ASEE) annual conference papers. Specifically, these papers show a steady increase in engineering education scholars’ usage of empathy; 17 publications used the term in some form in 2012, 23 in 2013, 38 in 2014, and 69 in 2015. The increase in ASEE papers using the term ‘caring’ was also steady; 41 articles used this term in 2012, compared to 297 in 2013, 306 in 2014, and 410 in 2015.

One of the core empathy foci within engineering literature pertaining to empathy and care is on ‘empathic design’ (Hess and Fila 2016). This is likely because empathic design has been depicted as the most ‘comprehensive category’ of human-centred design (Kouprie and Sleeswijk Visser 2009; Zoltowski, Oakes, and Cardella 2012). However, beyond empathic design, much engineering education literature describes efforts to incorporate empathy and care into engineering curricula, with foci ranging from improving engineering students’ communication abilities (Walther, Miller, and Kellam 2012), idea generation potential (Gray et al. 2015), or community engagement (Zoltowski, Cummings, and Oakes 2014). In regards to caring, much of this literature focuses on the impact that caring faculty have on student learning (Akili 2015); the role of an ‘ethic of care’ in making ethical decisions (Kardon 2005; Pantazidou and Nair 1999); care within humanitarian efforts (Campbell and Wilson 2011); or standards of caring (ASCE Steering Committee 2006; Kardon 2005).

When considering gender, care has been depicted as a ‘feminine’ quality (Noddings 1984) and hence one might anticipate that males would be less empathic or caring than females in any context. Indeed, females tend to self-report being more empathic than males, although the gender gap appears to lessen with age (Schieman and Van Gundy 2000) or through explicit training (Hatcher et al. 1994). Therefore, we might anticipate that female engineers would perceive empathy and care to be more applicable to their work when compared to their male counterparts, although this trend may not hold for more experienced engineers. A few studies have found subtle gender differences in the self-reported empathic tendencies of engineering students (Hess et al. 2015; Rasoal, Danielsson, and Jungert, 2012). Similarly, Woodcock et al. (2013) found that female engineering students tend to be more person-oriented and communal-focused than their male counterparts, which may translate to a difference in empathy and caring dispositions. Nonetheless, a more concerted focus on these phenomena is needed, particularly within the professional engineering context while taking gender, age, and experience into consideration.

Conceptualising empathy and care within engineering

Despite the rapid emergence of literature on empathy and care within engineering, seldom do scholars articulate their conceptualisations of these phenomena. What is more, as Strobel et al. (2013) indicated, when grounded in the context of engineering, empathy and care may take on distinct meanings when compared to traditional contexts. Yet, the survey described in this study gauged to what extent engineers perceive empathy and care to exist within and be important to the practice of engineering.

The conceptual framing of this study comes directly from Hess, Strobel, and Pan (2016) who explored practicing engineers’ conceptual understanding of empathy and care. Specifically, these authors explored how practicing engineers conceptualise (a) empathy, (b) care, and (c) differentiate between the two by thematically analysing semi-structured interviews with practicing engineers.

Through this qualitative research process, Hess, Strobel, and Pan (2016) found that engineers conceptualised empathy in four ways: cognitively or as a form of perspective taking, as embodiment or internalising another’s condition, connectedness or thinking about the interplay between other stakeholders and one’s self, and as an outcome or understanding of stakeholders and society. Likewise, engineers conceptualised care in four ways: as concern or an emotive other-centric feeling, behaviourally or as an action response, motivationally or as the intrinsic drive to achieve a goal, and as duty or acting in accordance with one’s professional obligation.

Further, participants perceived a strong relationship between empathy and care. With respect to the inter-relation between the two phenomena, most notably, the majority of participants perceived care to be a behavioural response resulting from empathy. Nonetheless, this did not capture the entire space of perceptions. Some participants considered empathy and care to be synonymous, whereas others emphasised the nuances between the two. Importantly, this latter group tended to emphasise the behavioural or compassionate nature of caring as building upon cognitive or experiential aspects of empathy.

Extending these qualitative insights, Hess, Strobel, and Pan (2016) conceptualised empathy and care as closely related phenomena that, when taken together, represent both understanding and feeling for others through a variety of techniques and, generally, acting on that understanding or internalisation. When responding to the survey items described in this study, participants responded to paired questions (e.g. ‘How important it is for engineers to show empathy and care in the following situations … ?’). We theorised that participants’ responses to this paired construct align with the conceptual framing that was surmised from Hess, Strobel, and Pan’s (2016) qualitative synthesis. In other words, this conceptual framing provided the groundwork for the quantitative exploration of practicing engineers’ perceived importance of these phenomena.

Methodology

This section on research methodology presents an overview of the research purposes and questions, the research design, and an overview of the design of the Empathy and Care Questionnaire (ECQ).

Research purpose and questions

Our first research purpose (Phase 1) was to design, explore the structure of, and validate the ECQ, an instrument for exploring practicing engineers’ perceptions of the importance and existence of empathy and care within engineering practice. Second, we sought to explore nuances in practicing engineers’ responses to the ECQ factor structure by comparing the derived factors with respect to one another, as well as demographically by respondents’ years of engineering work experience and gender (Phase 2). Taken together, the following research questions and sub-questions guided this inquiry:

- RQ1: What is the underlying factor structure of the ECQ?
    - To what extent is the instrument valid and reliable?
- RQ2: Using this ECQ factor structure, to what extent do practicing engineers perceive empathy and care to already exist within their practice and in what areas would a greater incorporation of empathy and care be most beneficial?
    - To what extent do responses vary by years of engineering work experience?
    - To what extent do responses vary by gender?

Research design

This study was divided into two phases with respect to each of the guiding research questions. In each phase, we used practicing engineers’ responses to survey items to explore the phenomena of empathy and care within engineering. This quantitative analysis was guided by a post-positivistic research paradigm (Borrego, Douglas, and Amelink 2009; Clark 1998). Specifically, in Phase 1, we designed and performed exploratory factor analysis (namely, principal component analysis) on a survey to gauge engineers’ perceptions of empathy and care within their work. In Phase 2, we used the derived factor structure to explore practicing engineers’ perceptions of empathy and care within engineering practice and to compare responses by years of experience and gender. This study is sequential, as we used the results from the derived factor structure (Phase 1) to explore nuances and compare variables (Phase 2).

ECQ design

As a research team, we designed the ECQ by building directly upon our team's previous research findings from two investigations. In the first, we synthesised literature on empathy and care within engineering (Strobel et al. 2011); for the ECQ design, we extracted and recorded ideas or keywords that were associated with empathy and care from this literature (e.g. making ethical decisions, see Vallero 2008; communication, see Leydens and Lucena 2009). In the second study, we captured perceptions of the importance of empathy and care through small-group interview sessions with engineering faculty and non-engineering faculty from fields traditionally perceived as empathetic and caring (Hess et al. 2012; Strobel et al. 2013). For the ECQ design, we refined verbal responses, particularly those undergirding qualitative themes, to capture domains where empathy and care appeared salient within engineering. By building directly on this work, we were striving to ensure the ECQ items accurately represented ideas that were salient within the practice of engineering, an essential component of construct validity (Messick 1995).

Individual members of the research team began creating potential survey items independently, with the broader themes and categories from the team's prior analyses guiding our item generation. Through an extended series of conversations, the research team continually refined, created novel, and altogether removed items. Throughout the process, we were cognisant of and open to incorporating ideas from literature on empathy and care within non-engineering fields, especially counselling (Berger 1987) and nursing (Kunyk and Olson 2001). Due to these discussions, the team moved from isolated survey items1 to categories that encapsulated multiple survey items.2 Further, we debated the specifics of the tense and verbiage of survey items. As an example, for items 1 through 12, we utilised the verb 'show' rather than 'feel' to emphasise the intent of action with respect to the overarching category.

To ensure construct validity (Douglas and Purzer 2015; Messick 1995), or the alignment between what the items are purported to measure and what they actually measure, we gathered feedback on near-final items from a content expert, thereby enhancing content relevance. In addition, an instrument and validation expert provided suggestions related to the survey structure, including the presentation of survey items and the choice of the six-point Likert-type scale. Finally, undergraduate and graduate student researchers completed a pilot survey (through Qualtrics) and provided feedback on the survey items, with a specific focus on whether the overall survey and individual items were clear.

In total, we refined these excerpts and responses into 33 Likert-type scale items pertaining to perceptions of the nature, importance, or manifestation of empathy and care within engineering practice (e.g. in identifying users' needs; in engineering communication; the extent to which they are learnable), and four 100-point items pertaining to participants' perceptions of the general importance of empathy and care in their lives and engineering practices. We did not theorise that these 100-point items would load onto the same facture structure as the 6-point Likert-type questions, but we anticipated that responses to these questions would be meaningful for exploring the nuance between empathy and care in one's life versus one's engineering practice. Appendix 1 provides an overview of the 37 items contained within the ECQ.

Phase 1: Exploratory factor analysis

Participant overview

We disseminated the ECQ to engineering alumni from a large public Mid-Western university within the USA. We invited more than 20,000 engineering alumni from this university to partake in the study. From that pool, 2148 participants at least opened the survey. We removed 524 of these participants for not completing the survey to the end and 50 more participants for failing to answer 6 or more questions. We chose this number in recognition that there are 'no guidelines for how much missing data is too much' (Harrington 2009, 38). Specifically, due to our exclusion strategy (we excluded participants pairwise), participants who did not respond to six or more questions were likely to be excluded from most (if not all) of the analysis.

After removing these 574 participants, 1574 participants from diverse engineering backgrounds and experiences remained for exploratory factor analysis (Phase 2 includes more specific demographic information). Of the 1574 respondents, 15 did not answer 3–5 questions, 18 did not answer 2, and 108 did not answer 1 question. Tabachnick and Fidell (2007) suggested that for large data sets with less than 5% missing points at random, any method of handling the data will likely not misrepresent the final result. In total, there were 141 missing data points among the 1574 respondents, or approximately 0.3% of the total possible item responses.

Exploratory factor analysis overview

Exploratory factor analysis is a data reduction technique for the development of scales, which in turn can allow for valid and reliable evaluations of a phenomenon (Beavers et al. 2013; Pallant 2010; Thompson 2004). Specifically, factor analysis explores the relationship between measured items (e.g. participants' ECQ-item responses), and determines whether these can be simplified to a number of constructs or factors. We began analysing the ECQ using principal component analysis (Netemeyer, Bearden, and Sharma 2003; Thompson 2004) to discover the primary interrelationships between ECQ items and to identify factors related to our participants' perceptions of the existence and importance of empathy and care in engineering practice. Throughout principal component analysis, we excluded questions 13–16 as these were set on a sliding scale of 1–100 whereas all other questions varied on a Likert-type scale of 1–6 (see Appendix 1). In Phase 2, we separately examined and analysed questions 13–16.

Principal component analysis is the most commonly used type of exploratory factor analysis (Irving and Dickson 2004; Netemeyer, Bearden, and Sharma 2003; Thompson 2004; Velicer and Jackson 1990). Its common usage might be, in part, because it is the default setting in many standard software packages, such as SPSS (Pallant 2010). Principal component analysis attempts to maximise the variance between the survey items while assuming perfect reliability on measured scores (e.g. the diagonal of the correlation matrix is restricted to all 1.0's), and then using this information to extract initial components (Thompson 2004). By removing items that explain little variance, the outcome of the analysis is 'the fewest number of meaningful components' (Netemeyer, Bearden, and Sharma 2003, 121).

Notably, there is a long-standing debate among behavioural researchers regarding whether principal component analysis is the 'best' factor analytic method, where 'some authorities insist that component analysis is the only suitable approach' while others hold that other factor analytic methods (e.g. principal axes factors analyses) are far superior (Cliff 1987, 349). Nonetheless, many scholars have suggested that the results of each method tend to be similar (Ogasawara 2000; Thompson 2004; Velicer and Jackson 1990), specifically when there are more than 30 survey items (the Phase 1 factor analysis includes 33 items) or when the communalities of most items exceeds .60 (Netemeyer, Bearden, and Sharma 2003). Hence, throughout this investigation, we describe the results as ‘factors’ rather than ‘principal components’ in light of this recognition, and due to the similarities in the outcomes of varying factor analytic methods.

Checking assumptions

Prior to performing principal component analysis, we assessed the suitability of the factorability of the data. Throughout these and all subsequent analyses, we excluded cases pairwise, where a participant’s response was dropped only from the computations pertaining to questions they did not answer. We would have used maximum likelihood estimation to fill in missing data, the strategy recommended by Harrington (2009), but because the ECQ responses exhibited a non-normal distribution (for most questions, the majority of participants provided favourable responses), this strategy could not be reliably applied (Enders 2001).

As a first check, we examined the inter-item correlation matrix. This revealed multiple coefficients greater than 0.3, hence supporting factorability of the data (see Tabachnick and Fidell 2007; Appendix 3 includes these results). Second, we checked the ratio of participants per question. Our sample included more than 47 participants per question, which was well above a suggested threshold of 10 participants per question (Nunnally 1978). Third, the Kaiser–Meyer–Olkin measure of sampling adequacy was 0.921, which suggested that factorability of the data was ‘marvellous’ (Beavers et al. 2013; Kaiser 1974). Fourth, Bartlett’s (1954) Test of Sphericity was significant ($p < .001$) further supporting factorability of the data.

Next, we explored which factor rotation strategy was most suitable. Factor rotation is a technique of ‘moving the factor axes measuring the locations of the measured variables in the factor space so that the nature of the underlying constructs become more obvious’ (Thompson 2004, 38). As several items showed loadings onto multiple factors when we initially utilised an orthogonal varimax rotation, we decided to switch to an oblique rotation. Specifically, we utilised a direct oblimin rotation with a delta of 0, as this is one of the most common oblique rotation strategies (Pallant 2010; Tabachnick and Fidell 2007). An oblimin rotation controls for the ‘degree of correlation among the rotated factors’, where the delta specification of zero ‘yields factors that are more highly correlated’ (Thompson 2004, 44).

Factor retention

Next, we explored how many ECQ factors to retain through a series of steps. First, we computed eigenvalues and checked how many were above 1.0, as this threshold is the theoretical cut-off representing where a factor encapsulates more than what would be captured by a single variable (Guttman 1954; Kaiser 1960). Principal component analysis revealed the presence of eight components meeting these criteria. The four-factor structure explained 49.2% of the total variance, whereas the total variance explained increased by roughly 3% when adding Factors 5, 6, 7, and 8, respectively (see Table 1).

Second, to check this initial result, we used parallel analysis, a method that generates a matrix of random variables that is similar to the matrix of items collected, and utilises this information to compute a set of eigenvalues, which are in turn used to deduce how many factors to retain (Horn 1965). Specifically, we generated criterion values, or randomly generated eigenvalues, by utilising the programme ‘Monte Carlo PCA (principal component analysis) for Parallel Analysis’ (Ed & Psych Associates 2011) and inputting 33 variables × 1574 respondents.

Table 2 shows the criterion values generated from this parallel analysis. Comparing these criterion values with actual eigenvalues from Table 2 suggested that we should retain six factors.

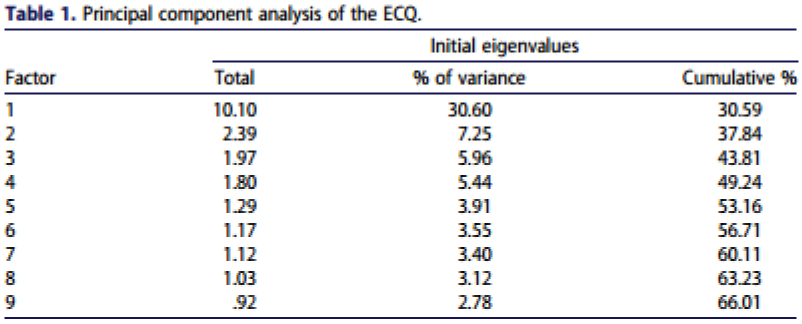


Table 1. Principal component analysis of the ECQ.

	Initial eigenvalues		
Factor	Total	% of variance	Cumulative %
1	10.10	30.60	30.59
2	2.39	7.25	37.84
3	1.97	5.96	43.81
4	1.80	5.44	49.24
5	1.29	3.91	53.16
6	1.17	3.55	56.71
7	1.12	3.40	60.11
8	1.03	3.12	63.23
9	.92	2.78	66.01

Third, we analysed Table 1 to decide if we should keep 6 or less factors. Fifty percent has been depicted as the lower threshold for accepting the factor analytic output, although many studies report variance prediction levels as high as 75% are preferable (Beavers et al. 2013). The fourfactor structure explained 49.2% of the variance, the five-factor structure explained 53.2%, and the 6-factor structure explained 56.7%. As the 50% criteria were met by the five- and six-factor solutions, but not the four-factor solution, we removed the latter from consideration.

Next, we computed and synthesised the pattern and structure matrices of the five- and six-factor structures. Pattern coefficients, contained within the pattern matrix, are analogous to beta weights in multiple regression; namely, they express the ‘the variance represented in the correlation matrix that is being analyzed’ (Thompson 2004, 16). Conversely, structure coefficients represent the bivariate correlation coefficient between a measured variable and the composite variable (e.g. the derived factor, see Thompson 2004). We used a threshold of 0.5 for identifying ‘strong’ pattern coefficients (Costello and Osborne 2005). In the six-factor solution, the sixth factor contained two items (e.g. Q21 and Q22) and a few items loaded highly on multiple factors (e.g. Q23 and Q11), making interpretation of the six-factor output difficult. Hence, we moved forward with the five-factor solution.

As a final check, we computed the communalities for the five-factor structure. The communalities describe how much of the variance of each item can be explained by the overall factor structure (Netemeyer, Bearden, and Sharma 2003; Thompson 2004). Netemeyer, Bearden, and Sharma (2003) suggested that if the majority of communalities are above .6, then the outcome is likely to be similar regardless of which factor analytic procedure was utilised (e.g. principal component analysis versus principal axes factor analysis). With the five-factor structure, several communalities were above .60 (8 of 33, or 24.2%), whereas the majority of communalities were at or greater than .55 (17 of 33, or 51.5%).

Due to these considerations, we chose to retain the five-factor structure. Here, the pattern matrix showed numerous strong item-loadings onto each of the factors and large item-communalities (see Appendix 2 for the pattern matrix and communalities). Lastly, we checked for consistency between the pattern and structure matrices. This synthesis indicated that three items had structure coefficients slightly above 0.50 but pattern coefficients of 0.42 or less (specifically Q11, Q22, and Q31). We chose the more conservative retention criteria, and therefore did not include these items within the final factor structure (described next).

Derived factor structure of the ECQ

The five factors derived from the exploratory factor analysis were internally consistent, although the fifth factor was ‘minimally’ acceptable as evident by its Cronbach’s α below .70 but above .60 (DeVellis 2011). We named these factors by re-examining the questions paired to each factor, including the question prompt and the specific questions themselves. Through dialogue and extensive conversations, we described each factor as follows:

1. The existence of empathy and care within engineering work and practice.
2. The importance of empathy and care within engineering work, in general.
3. The potential benefits of a greater inclusion of empathy and care into engineering.
4. The value of empathy and care in relational aspects of engineering work.
5. The extent to which empathy and care are considered learnable.

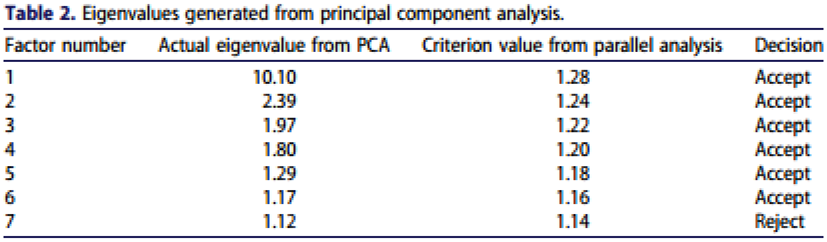


Table 2. Eigenvalues generated from principal component analysis.

Factor number	Actual eigenvalue from PCA	Criterion value from parallel analysis	Decision
1	10.10	1.28	Accept
2	2.39	1.24	Accept
3	1.97	1.22	Accept
4	1.80	1.20	Accept
5	1.29	1.18	Accept
6	1.17	1.16	Accept
7	1.12	1.14	Reject

Table 3 shows the items paired to each of these factors, along with their internal consistency reliability, as ascertained by calculating Cronbach’s α (Cronbach 1951). The italic items in the pattern matrix (e.g. those with 0.50 or greater pattern coefficients) included in Appendix 2 make up this five-factor structure. Cronbach’s α for the first four factors were highly reliable (e.g. α > .80), whereas Factor 5 was only minimally reliable (e.g. in the .6–.7 range, see DeVellis 2011). Appendix 1 shows complete item descriptions, means, and standard deviations of the individual survey items, and Appendix 4 shows inter-factor correlations.

Phase 2: Quantitative comparisons using the ECQ

In this section, we used the ECQ’s derived factor structure (from Phase 1) to compare responses of each factor with respect to one another, as well as differences in factor responses by demographics (e.g. by years of engineering work experience and by gender).

Participant overview

After deriving the factor structure through exploratory factor analysis, we removed 93 participants who did not provide information on gender or years of work experience, along with those who did not have any experience working in engineering after graduation. The gender distribution of the remaining 1481 respondents included 1198 males (~81%) and 283 females (~19%). The average participants’ years of engineering practice was 23.8 with a 13.6-year standard deviation. However, a closer inspection of these findings portrayed that the female respondents tended to have fewer years of experience than the male participants. For example, the average male respondent’s years of engineering practice was 25.9 with a 13.7-year standard deviation, whereas the average female respondent’s was 14.9 years with a 9.2-year standard deviation. Notably, no female participants had more than 40 years of engineering experience, and only 27 (approximately 10% of the female respondents) had more than 30 years of experience. Table 4 provides an overview of the experiential distribution for all participants and by gender.

We asked participants which engineering degree they received and in which discipline(s) they were currently working. Figure 1 shows the engineering degree that participants graduated with, alongside their current profession(s). For each question, we allowed participants to select multiple disciplines; hence, many more respondents selected ‘multi-disciplinary’ as their current work when compared to their engineering degree.

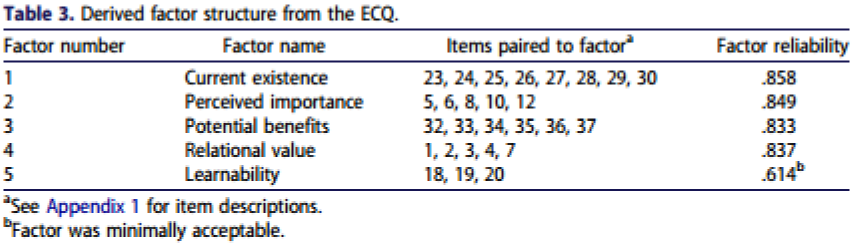


Table 3. Derived factor structure from the ECQ.

Factor number	Factor name	Items paired to factor[a]	Factor reliability
1	Current existence	23, 24, 25, 26, 27, 28, 29, 30	.858
2	Perceived importance	5, 6, 8, 10, 12	.849
3	Potential benefits	32, 33, 34, 35, 36, 37	.833
4	Relational value	1, 2, 3, 4, 7	.837
5	Learnability	18, 19, 20	.614[b]

[a] See Appendix 1 for item descriptions.

[b] Factor was minimally acceptable.

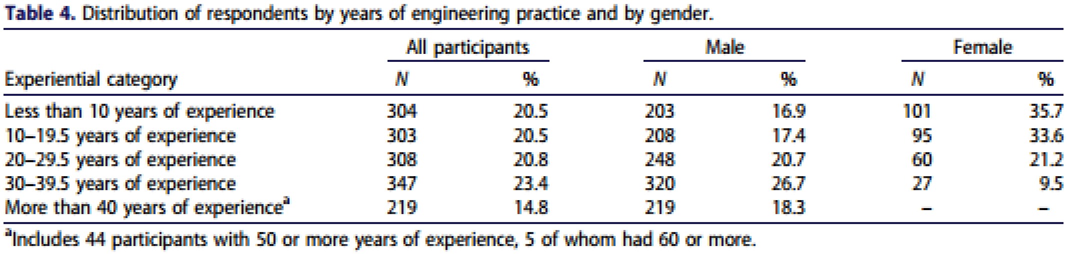


Table 4. Distribution of respondents by years of engineering practice and by gender.

	All participants		Male		Female	
Experiential category	*N*	%	*N*	%	*N*	%
Less than 10 years of experience	304	20.5	203	16.9	101	35.7
10–19.5 years of experience	303	20.5	208	17.4	95	33.6
20–29.5 years of experience	308	20.8	248	20.7	60	21.2
30–39.5 years of experience	347	23.4	320	26.7	27	9.5
More than 40 years of experience[a]	219	14.8	219	18.3	–	–

[a] Includes 44 participants with 50 or more years of experience, 5 of whom had 60 or more.

Factor comparisons

For each participant, we calculated their factor score by taking the average of the items that loaded onto each factor (see Table 3). Therefore, factor responses were set on a 6-point Likert-type scale, similar to the items.

Figure 2 shows average responses to each factor, with the factors presented in order from highest to lowest mean/median score. As Figure 2 shows, the ‘relational’ factor received the highest average responses whereas the ‘learnable’ factor received the lowest. This indicated that participants were most favourable to the idea that empathy and care were important in relational aspects of engineering work, but they were least inclined to agree that empathy and care were learnable. The differences between responses to the ‘importance’ and ‘existence’ factors were particularly surprising; in essence, this suggests that there exists a disjuncture between the perceived importance and current existence of empathy and care within engineering practice.

Next, we analysed whether differences between factors were statistically significant. We utilised non-parametric tests because normality assumptions were violated, as evident by examining the distribution of the factor histograms (each was skewed to the left) and by calculating the Shapiro–Wilks (1965) coefficients ($p < .001$ for each factor). Therefore, we performed a series of related-samples Wilcoxon Signed Rank test (Wilcoxon 1945). This test compares the median difference between two related samples (in this case, factors) by exploring differences between the central tendency of the samples, or the factor medians (Howell 2010; McCrum-Gardner 2008). These analyses indicated that responses to each of the highest ranked factors (see Figure 2) were significantly greater than those for each lower-ranked factor (F4 and F2, Z = 26.2; F2 and F3, Z = 9.4; F3 and F1, Z = 10.6; F1 and F4, Z = 31.5; p < .001 for each).

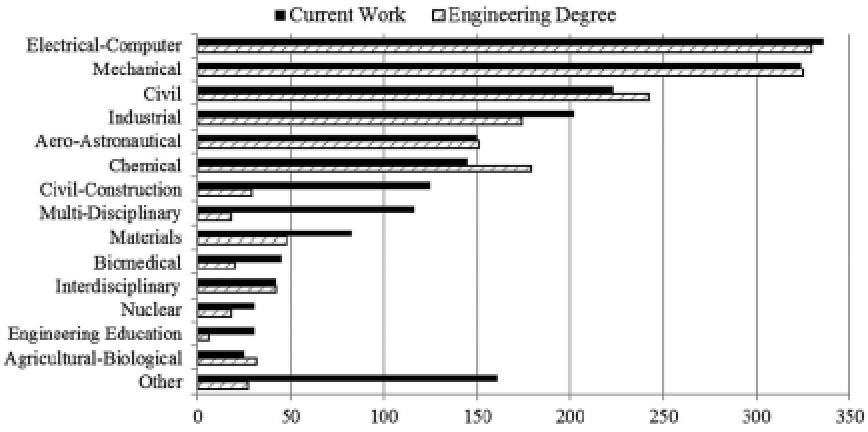


Figure 1. Engineering practice(s) and engineering degree of the survey sample.

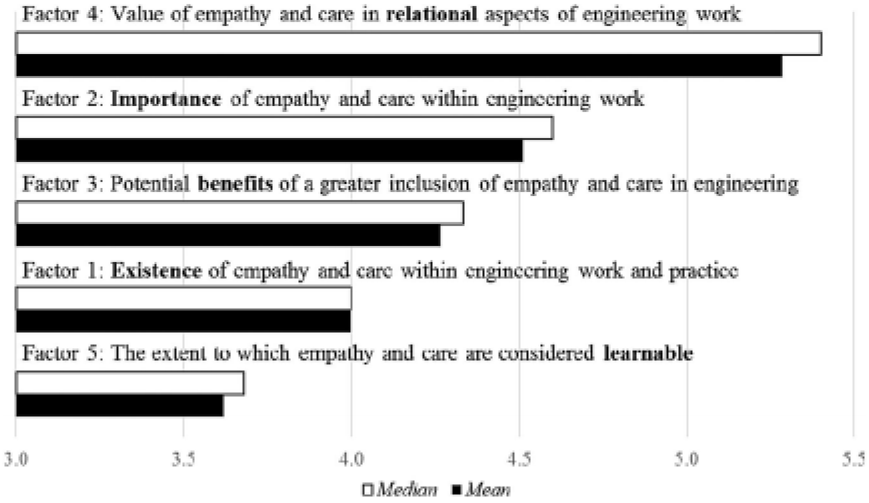


Figure 2. Respondents' mean and median factor responses, ordered highest to lowest.

In Q13 and Q14, we asked participants to rate how important empathy and care were for them 'as an individual' and in Q15 and Q16, we asked participants to rate how important empathy and care were for them 'as an engineer'; these responses were recorded by a sliding scale that ranged from 1 to 100. First, we ascertained the reliability, mean, and standard deviation of participants' combined responses to the 'importance as an individual' (Mdn = 85; $\mu = 82.4$, $\sigma = 14.1$, $\alpha = .79$) and 'importance as an engineer' (Mdn = 78; $\mu = 75.1$, $\sigma = 17.6$, $\alpha = .80$) items, and found the internal consistency of each to be good (DeVellis 2011). Next, we compared the combined responses by using a related-samples Wilcoxon Signed Rank test (Wilcoxon 1945). This analysis indicated that respondents considered empathy and care to be more important for them as an individual than as an engineer (Z = −21, p < .001).

Demographic comparisons

In this section, we compared how respondents with varying years of engineering work experiences and how males versus females responded differently to the ECQ factors. These tests started with the assumption that participants in different groups would respond similarly to each factor. We used nonparametric testing procedures throughout these analyses, as normality assumptions were violated (Howell 2010; McCrum-Gardner 2008).

Comparing ECQ results by experience

We stratified participants into five groups based on the number of years they had worked in engineering. The first four groups increased by 10-year sequences (e.g. less than 10 years of experience, 10– 19.5 years), whereas the last group encapsulated all participants with more than 40 years of experience. As Table 5 shows, the most experienced group consistently responded the most favourably to each factor. Notably, responses increased for each group (e.g. the 30–39.5 year group always scored higher than the 20–29.5 year group, who always scored higher than the 10–19.5 year group).

Next, we tested whether years of engineering work experiences influenced responses by performing independent samples Kruskal–Wallis tests for each factor (Kruskal and Wallis 1952). Kruskal–Wallis testing is the non-parametric alternative to the one-way analysis of variance. Specifically, it compares the variation of central tendency responses across multiple groups (Howell 2010; McCrum-Gardner 2008). Throughout this analysis, the null hypothesis for each test was that the median responses across groups on each factor were equal. This analysis indicated that there was a statistically significant difference in factor responses between the different experiential groups (see Table 5).

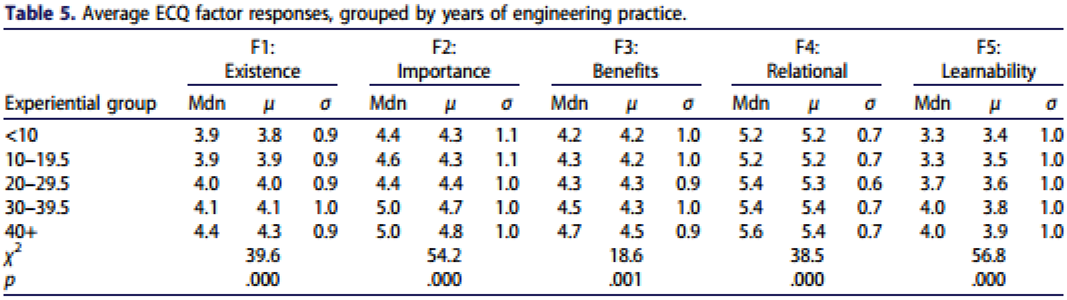


Table 5. Average ECQ factor responses, grouped by years of engineering practice.

	F1: Existence			F2: Importance			F3: Benefits			F4: Relational			F5: Learnability		
Experiential group	Mdn	μ	σ	Mdn	μ	σ	Mdn	μ	σ	Mdn	μ	σ	Mdn	μ	σ
<10	3.9	3.8	0.9	4.4	4.3	1.1	4.2	4.2	1.0	5.2	5.2	0.7	3.3	3.4	1.0
10–19.5	3.9	3.9	0.9	4.6	4.3	1.1	4.3	4.2	1.0	5.2	5.2	0.7	3.3	3.5	1.0
20–29.5	4.0	4.0	0.9	4.4	4.4	1.0	4.3	4.3	0.9	5.4	5.3	0.6	3.7	3.6	1.0
30–39.5	4.1	4.1	1.0	5.0	4.7	1.0	4.5	4.3	1.0	5.4	5.4	0.7	4.0	3.8	1.0
40+	4.4	4.3	0.9	5.0	4.8	1.0	4.7	4.5	0.9	5.6	5.4	0.7	4.0	3.9	1.0
χ^2		39.6			54.2			18.6			38.5			56.8	
p		.000			.000			.001			.000			.000	

Next, we analysed whether years of work experience influenced how important practicing engineers perceived empathy and care was for them ‘as an engineer’ or ‘as an individual’. An inspection of group responses indicated that the mean and median scores increased for each experiential group in response to the ‘as an engineer’ items, as shown in Table 6. However, this same trend did not hold for the combined responses to ‘as an individual’. Next, we utilised independent samples Kruskal–Wallis (Kruskal and Wallis 1952) tests on the combined responses to Q13/14 and Q15/16. This analysis indicated that work experience significantly influenced engineers’ ratings of the importance of empathy and care for them ‘as an engineer’ ($\chi2 = 51.7$, $p < .001$) and ‘as an individual’ ($\chi2 = 10.5$, $p < .05$).

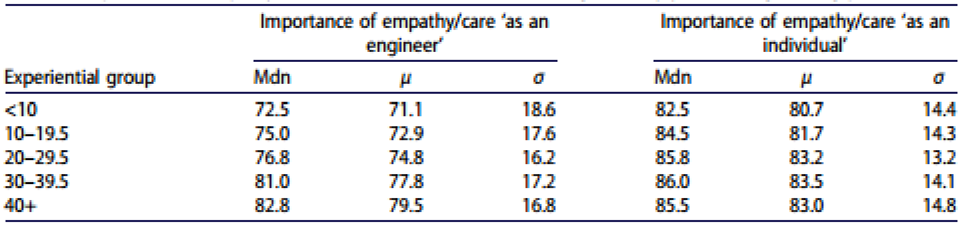
Comparing ECQ results by gender

Next, we explored the extent to which males and females responded to the ECQ factors differently. Throughout this analysis, we took into account the experiential findings and the demographic distribution, namely, that the majority of female respondents had practiced engineering for less than 30 years (see Table 4). Hence, we chose to compare responses by gender with respect to the same 10- year experiential distribution (e.g. less than 10 years, 10–19.5 years, and 20–29.5 years of experience).

Table 7 provides descriptive statistics, including mean and standard deviations, grouped by gender and years of engineering experience for each of the ECQ factors. Within each experiential group, and for each factor, the difference between male and female participants' average responses range from 0.20 to 0.01. Next, we compared these responses by gender and by using a series of independent samples Mann–Whitney U tests (Mann and Whitney 1947). In each, we tested the hypothesis that males and females, within the specified experiential group, would not respond significantly differently to each factor. We did not find gender to influence responses to any of the factors within any of the experiential groups, indicating that male and female responses to these factors were similar.

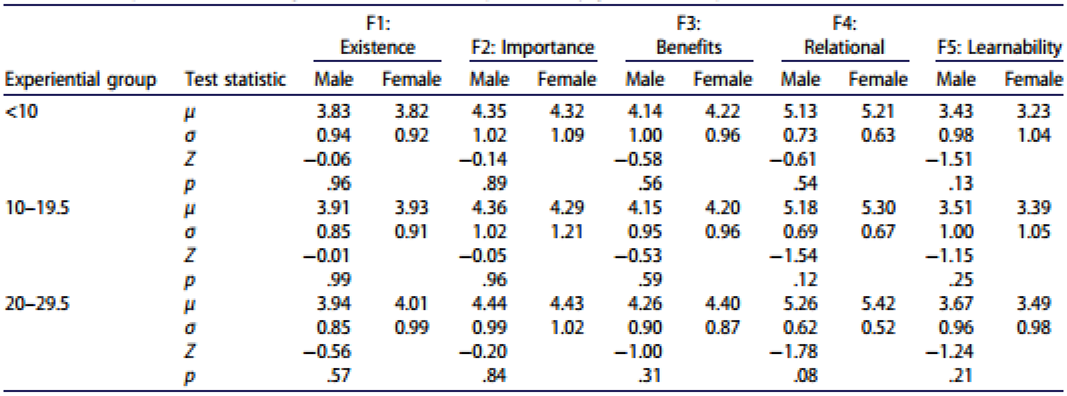
Next, we analysed the extent to which gender influenced how important practicing engineers perceived empathy and care to be for them 'as an engineer' and 'as an individual' by using independent samples Mann–Whitney U tests (Mann and Whitney 1947). Our analyses indicated that females within the 10–19.5 years of experience reported that empathy/care was more important for them 'as an individual' than male respondents from the same experiential group (see Table 8; $p < .05$). We did not find any other significant differences.

Table 6. Importance of empathy/care as an 'individual' and as an 'engineer', by years of engineering practice.



	Importance of empathy/care 'as an engineer'			Importance of empathy/care 'as an individual'		
Experiential group	Mdn	μ	σ	Mdn	μ	σ
<10	72.5	71.1	18.6	82.5	80.7	14.4
10–19.5	75.0	72.9	17.6	84.5	81.7	14.3
20–29.5	76.8	74.8	16.2	85.8	83.2	13.2
30–39.5	81.0	77.8	17.2	86.0	83.5	14.1
40+	82.8	79.5	16.8	85.5	83.0	14.8

Table 7. Descriptive statistics along ECQ factors for all respondents by gender and experience.



		F1: Existence		F2: Importance		F3: Benefits		F4: Relational		F5: Learnability	
Experiential group	Test statistic	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
<10	μ	3.83	3.82	4.35	4.32	4.14	4.22	5.13	5.21	3.43	3.23
	σ	0.94	0.92	1.02	1.09	1.00	0.96	0.73	0.63	0.98	1.04
	Z	−0.06		−0.14		−0.58		−0.61		−1.51	
	p	.96		.89		.56		.54		.13	
10–19.5	μ	3.91	3.93	4.36	4.29	4.15	4.20	5.18	5.30	3.51	3.39
	σ	0.85	0.91	1.02	1.21	0.95	0.96	0.69	0.67	1.00	1.05
	Z	−0.01		−0.05		−0.53		−1.54		−1.15	
	p	.99		.96		.59		.12		.25	
20–29.5	μ	3.94	4.01	4.44	4.43	4.26	4.40	5.26	5.42	3.67	3.49
	σ	0.85	0.99	0.99	1.02	0.90	0.87	0.62	0.52	0.96	0.98
	Z	−0.56		−0.20		−1.00		−1.78		−1.24	
	p	.57		.84		.31		.08		.21	

Discussion

In this study, we designed and explored the factor structure of the ECQ to elucidate engineers' perceptions of the importance and existence of empathy and care within engineering practice. This investigation found that more experienced engineers were more favourable to each of the five factors that emerged from principal component analysis of the ECQ, suggesting that an increase in engineering experience directly correlates with engineers' perceived importance and awareness of empathy and care within engineering practice. Comparing responses by gender indicated that male and female participants responded similarly to all ECQ factors. In the following sections, we explore the results from the factor analysis and factor comparisons, followed by the experiential and gender comparisons. We end by considering implications of these findings for engineering education.

Factor outcomes and comparisons

Exploratory factor analysis of the 33 Likert-type questions from the ECQ revealed five factors representing practicing engineers' perceptions of the current existence (F1), general importance (F2), potential benefits (F3), relational value (F4), and learnability (F5) of empathy and care within engineering. Comparisons of these factors with respect to one another led to several insights regarding the need for and relative value of a greater integration of empathy and care within engineering practice.

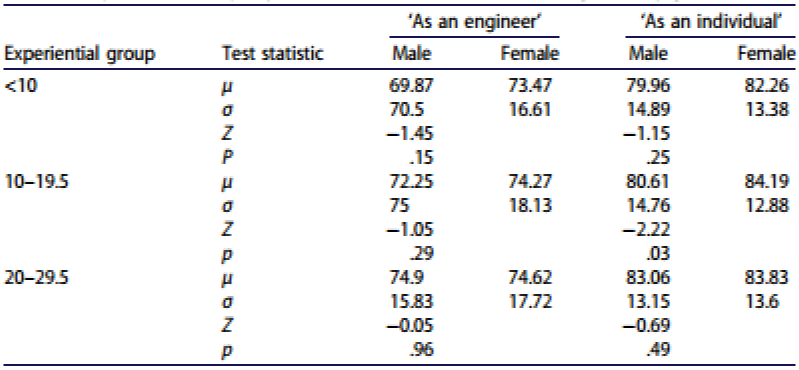


Table 8. Importance of empathy/care as an 'individual' and as an 'engineer', by gender.

		'As an engineer'		'As an individual'	
Experiential group	Test statistic	Male	Female	Male	Female
<10	μ	69.87	73.47	79.96	82.26
	σ	70.5	16.61	14.89	13.38
	Z	−1.45		−1.15	
	P	.15		.25	
10–19.5	μ	72.25	74.27	80.61	84.19
	σ	75	18.13	14.76	12.88
	Z	−1.05		−2.22	
	p	.29		.03	
20–29.5	μ	74.9	74.62	83.06	83.83
	σ	15.83	17.72	13.15	13.6
	Z	−0.05		−0.69	
	p	.96		.49	

First, factor comparisons indicated that practicing engineers perceived empathy and care as most important within relational aspects of engineering work. This finding was not entirely surprising, as interventions have already been designed to develop engineering students' empathic communication skills (Leydens and Lucena 2009; Walther, Miller, and Kellam 2012). Likewise, the emphasis on the relational importance of empathy and care for effective communication has been described extensively within counselling (Berger 1987; Rogers 1951) and nursing (Kunyk and Olson 2001) literature. However, we were surprised by the marked difference between participants' mean response to the 'Relational' factor ($\mu = 5.28$) and the next closest factor, labelled 'Importance' ($\mu = 4.51$), which encapsulated elements related to the broader impact of engineering decisions.

Second, we found a significant difference between participants' perceptions of the importance ($\mu = 4.51$) and the existence ($\mu = 4.00$) of empathy and care within engineering practice. While the 'Importance' factor contained elements related to the broader impact of engineering decisions, the 'Existence' factor captured how established or integrated participants felt concepts related to empathy and care were incorporated into their own work, as well as their colleagues’ practices, their workplaces’ cultures, and their professions’ ethos. Given the importance of empathy and care in both relational and broader impact aspects of engineering practice, these findings point to a critical need to identify strategies to bridge this disconnect. Hence, this finding connects with many of the recent calls for change in engineering education (Grasso and Burkins 2010; National Academy of Engineering 2004, 2005, 2009), but it specifically highlights a need for including empathy and care within these change paradigms.

Third, factor comparisons indicated that practicing engineers were least inclined to agree that empathy and care were learnable. However, a closer inspection of the mean responses to the individual items corresponding to this factor (see Appendix 1) indicated that its dismal average was largely reduced by Q20, ‘I learned to be more empathetic and caring during my college years.’ Indeed, this was the only item from the ECQ which had a below-average mean score (e.g. below the Likert-type scale mid-point of 3.5). This suggests that students’ collegiate experiences of years past have been particularly ineffective at instilling these skills/dispositions. This finding resonates with the work of Rasoal, Danielsson, and Jungert (2012), who found that engineering students were less empathic than students from fields such as social work and psychology. Given the importance of empathy and care to the practice of engineering, this indicates that a direct focus on empathic development with engineering curricula is needed.

What is more telling is that the mean response to Q18, ‘I believe traits associated with empathy and care can be learned,’ was well above the mid-point of responses. Therefore, it did not appear that participants felt empathy and care could not be learned, but rather that they did not perceive to have learned these skills in college. What is more pressing, however, is that today’s U.S. collegiate students report being much less empathic than students from years past, as indicated by a metaanalysis of 72 colleges (Konrath, O’Brien, and Hsing 2011). Yet, others have found that training in empathic skills can catalyse collegiate students’ cognitive and affective empathic development (Hatcher et al. 1994). We encourage engineering educators to build on these findings within the context of engineering education, specifically.

Lastly, despite the above findings, participants indicated that empathy and care were much more important for them ‘as an individual’ than ‘as an engineer’. While many scholars have recently deemphasised the divide between the ‘soft’ and ‘hard’ skills of engineering practice (Fila et al. 2014; Hynes and Swenson 2013; Strobel et al. 2013), it appears that there is an existing disconnect between the amount of empathy and care engineers use within their practice versus their daily livelihoods, even among participants who find empathy/care important to their practice. To the extent that this divide cannot be bridged, this dichotomy might be particularly problematic for encouraging highly empathic and caring individuals to pursue engineering degrees (Borrego et al. 2005).

Experiential comparisons

Comparing the ECQ factors by experiential groups indicated that with more work experience, practicing engineers become more conscious of the existence of and more favourable towards the importance of empathy and care within engineering. These same trends surfaced when comparing responses to the 100-point items on participants’ perceived importance of empathy and care for them ‘as an engineer’. Conversely, this upward trend increased up to but stabilised after the 20– 29.5 year experiential group when exploring participants’ perceived importance of empathy and care ‘as an individual’. While we could not find any scholarly sources that quantitatively explored changes in empathy and care due to engineering experiences, there is literature on changes in empathy with age that might help explain these findings. However, these investigations explore changes in empathic abilities or tendencies, rather than perceptions of empathy and care (as in this study). Further, these studies are not engineering-specific. We describe these sources next.

Cooper (2011) suggested empathy increases with age because older individuals have learned more in total and have had a greater variety of life experiences than younger individuals. Cooper's proposition was that increased knowledge and experience simultaneously increases the likelihood that one will relate to others, try to understand novel viewpoints, and thereby empathise. In the context of engineering, this might suggest that individuals who have practiced engineering longer begin to realise the social impact of their work.

Yet, contrary to Cooper's suggestion, numerous studies have found empathy to decline with age (Schieman and Van Gundy 2000), sometimes strictly with respect to cognition (Bailey, Henry, and Von Hippel 2008; Orgeta and Phillips 2008; Slessor, Phillips, and Bull 2007), but other times along the affective dimension (Phillips, MacLean, and Allen 2002; Ruffman et al. 2008). Likewise, Decety and Michalska (2010) compared differences in brain regions activated upon an empathic and sympathetic 'pain' stimuli between adults as old as 40 and children as young as 7. These neuroscientists found adults were less likely than children to respond affectively due to 'reduced activity within limbic affect processing systems' due to ageing (896).

Despite these investigations, a 12-year longitudinal study by Grühn et al. (2008) found empathy to be relatively stable with ageing. Specifically, while descriptive statistics revealed that older adults in their sample were less 'empathic' than younger adults, their longitudinal analysis did not reveal a decline of empathy among the older group. Instead, they posited there was a 'cohort effect' at play. In other words, rather than attributing empathic dispositional differences to ageing, these authors suggested that one's empathic development is contingent upon their interactions with others and their life satisfaction. Importantly, these suggestions align with Shieman and Van Gundy's (2000) assertion that certain experiences can mitigate this effect, including higher education, positive interpersonal relationships, and religious involvement.

Taken together, these studies suggest that there is much empirical work left to determine the best predictors of empathy gains or losses throughout one's life, including within and beyond engineering. It may be that specific variables, such as an engineer's life satisfaction, increases with engineering experience, and that this in turn influences their empathic tendencies. An insightful, longitudinal study might examine changes in empathic or caring tendencies of engineers as they progress in experience, perhaps in relation to their perceptions (e.g. by utilising the ECQ). Such an investigation could identify what experiences promote or inhibit empathic development throughout one's career, which could in turn provide engineering educators and organisational leaders with insights as to which interventions are most beneficial for empathic development.

Gender comparisons

Engineering has been described as male-dominated, uncaring, and even marginalising to women (Broom, Klassen, and Labun 2011; Foor et al. 2013; Godfrey and Parker 2010; Hess et al. 2012; Tonso 2006). These stereotypes might permeate engineering discourse because throughout the USA, males continue to be represented much more widely throughout engineering practice than women (e.g. see Falkenheim and Burrelli 2012; National Academy of Engineering 2008), which may lead to a lack (or a perception of a lack) of inclusion of divergent value systems (e.g. femininity, see Gilligan 1982; Noddings 1984) within engineering practice. For example, Foor et al. (2013) found that two separate female engineering students who worked alongside only male colleagues faced numerous challenges arising from stereotyped gender roles and work schemas. The authors concluded that the lack of women participating in their programme was 'not due to a lack of interest but to structural and cultural factors that are far from inclusive' (354). In other studies, it has been reported that female students may leave engineering out of a desire to help others, specifically towards a profession where they envision a social good component that they perceive as missing from engineering (Borrego et al. 2005; Sax 1994).

Yet, our analysis did not reveal any significant differences when comparing the ECQ factor responses by gender. The only significant difference we did find was that females with 10–19.5 years of experience perceived empathy and care to be more important for them 'as an individual' than the experientially equivalent male group. Hence, the findings from this investigation indicate that male and female engineers both equally perceive empathy and care as important in their engineering practice, despite both groups' pessimism towards the current existence of empathy and care in engineering. Therefore, promoting an 'ethic of care' (Pantazidou and Nair 1999) within engineering, while sometimes depicted as a feminine value (Gilligan 1982; Noddings 1984), seems to have relatively equal appeal to both male and female engineers. To some extent, these findings may be explained by the reality that many women engineers assimilate male-oriented engineering values in order to make it as an engineer, thereby becoming 'one-of-the-boys', as opposed to challenging their organisations to incorporate values that may be depicted as 'feminine' (Tonso 2006). Alternatively, male engineers may be more attuned with empathic and caring values than dominant stereotypes suggest.

Implications

Much of the literature in scholarly disciplines outside of engineering support the theory that empathy and care and associated skills are learnable in college and beyond (Erera 1997; Shapiro, Morrison, and Boker 2004). Existing strategies employed by other disciplines have focused on (a) strengthening emotional intelligence (Goleman 1995), (b) self-reflection (Rogers 1951), (c) developing active listening and communication abilities (Erera 1997), (d) human-centred design strategies (Zoltowski, Oakes, and Cardella 2012), and (e) using interactive, role-play, and simulation technology (McQuiggan and Lester 2006). Similarly, within engineering, Hess's (2015) investigation indicated that graduate level engineering students experienced changes in their perspective-taking tendencies due to their experiences within a structured, ethics intervention.

While many other strategies for the development or usage of empathy within engineering education are rapidly growing (Gray et al. 2015; Johnson et al. 2014; Walther, Miller, and Kellam 2012; Zoltowski, Oakes, and Cardella 2012), a concerted research focus on outcomes centred around engineering-specific training methods is needed. Foor, Walden, and Trytten (2007) regarded higher education to be the transmitter of 'dominant culture' (111). If empathy and care are important for the practice of engineering, as respondents within this study have indicated, then we must find mechanisms for a greater integration of these phenomena within engineering and engineering education. Future research questions engineering educators might investigate to effectively integrate empathy and care into engineering include (a) to what extent is the engineering education system attracting empathetic and caring individuals to engineering and how might we attract more?, (b) how empathic and caring is engineering perceived by non-engineers and how can we change these images?, and (c) for current engineers and engineering students, what are the best strategies for developing their empathic and caring tendencies?

Conclusion

This study has explored practicing engineers' perceived importance of empathy and care within the practice of engineering through the development and application of the ECQ. Engineering participants suggested a greater inclusion of empathy and care within the culture of engineering has the potential to improve engineering practice along multiple facets. Findings from our analysis showed that with increased years of work experience, respondents became more favourable to all ECQ factors, including the extent to which empathy and care were perceived as existing within and important to engineering practice. Furthermore, the majority of participants responded favourably to all items with one exception; participants felt that they did not become more empathic or caring through their own collegiate experiences. This suggests that departmental and school faculty ought to focus on developing and implementing pedagogical strategies for fostering these skills within engineering curricula.

Limitations and future work

As a proxy-indicator of empathy and care within engineering, this analysis is limited in its scope as it provides insight into the perceptions of individual engineering graduates from a single Mid-western large public engineering university within the USA. Hence, the generalisability of this study may be questioned, as one may consider the participants to be products of the culture of the particular university. We believe this is not a significant limitation, as most participants have graduated and been employed for long periods.

A second limitation is that participants in this study were potentially those primarily interested in the subject topic, as indicated by the normality assumption not met and the approximate 10% response rate. Yet, in considering the relative importance of the ECQ factors, as we did, we feel that these potential biases are unproblematic for the findings reported herein.

Lastly, the 53.2% variance captured by the retained ECQ factors indicates that there is much terrain related to engineers' perceptions of empathy and care not captured by the ECQ. Future investigations might extend the growing body of work (both qualitative and quantitative) on empathy within engineering to extend the ECQ into these terrains. For example, researchers might expand on the 'Learnability' factor by adding items pertaining to respondents' experiences in engineering classes, college in general, life, and their practice; depending on the scope of the research questions, these items may create sub-constructs mapped to the larger 'Learnability' construct. Likewise, investigators who modify and extend the ECQ might simultaneously explore the empathic and caring dispositions of engineering practitioners through other validated instruments, and they might explore how these dispositions influence their perceptions and vice versa.

Notes

1. For example, 'Do you enjoy working with team members that would be considered more empathetic?'

2. For example, ‘Based on your experiences in engineering, rank how important it is for engineers to show empathy and care in the following situations … ’ with the first item, ‘Working in teams’, the second item, ‘Meeting a client’s needs’, and so on (see Appendix 1).

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Appendix 1. Empathy and Care Questionnaire

Based on your experiences in engineering, rank how important it is for engineers to show empathy and care in the following situations. Select from 1 to 6, considering 1 as ‘not important at all’ and 6 as ‘very important’.

1. Working in teams, $\bar{x}$ = 5.00, s = 0.97
2. Meeting a client’s needs, $\bar{x}$ = 5.40, s = 0.86
3. Communicating with others, $\bar{x}$ = 5.26, s = 0.85
4. Listening to others, $\bar{x}$ = 5.37, s = 1.45
5. Ensuring that a design meets environmental regulations, $\bar{x}$ = 4.27, s = 1.29
6. Ensuring that the jobsite/work place is safe, $\bar{x}$ = 4.87, s = 0.83
7. Treating others respectfully, $\bar{x}$ = 5.39, s = 1.19
8. Making ethical decisions, $\bar{x}$ = 5.22, s = 1.39
9. Performing community service, $\bar{x}$ = 4.18, s = 1.39
10. In your design work, $\bar{x}$ = 4.07, s = 1.39
11. Stakeholder considerations, $\bar{x}$ = 4.48, s = 1.25
12. Sustainability considerations, $\bar{x}$ = 4.21, s = 1.24

Based on your personal life, rate how important each of these constructs is FOR YOU as an INDIVIDUAL on a scale of 0–100 with 0 meaning ‘not at all important’ and 100 meaning ‘very important’.

13. Empathy, $\bar{x}$ = 80.93, s = 16.29

14. Care, $\bar{x}$ = 83.93, s = 14.76

Based on your work experiences, rate how important each of these constructs is FOR YOU as an ENGINEER on a scale of 0–100 with 0 meaning ‘not at all important’ and 100 meaning ‘very important’.

15. Empathy, $\bar{x}$ = 72.63, s = 20.03

16. Care, $\bar{x}$ = 77.51, s = 18.42

Please rate how strongly you agree or disagree with the statement below. Select from 1 to 6, considering 1 as ‘strongly disagree’ and 6 as ‘strongly agree’.

17. I believe traits associated with empathy and care are part of who you are. $\bar{x}$ = 5.08, s = 1.08

18. I believe traits associated with empathy and care can be learned. $\bar{x}$ = 4.37, s = 1.169

19. I learned to be more empathetic and/or caring during my work as an engineer. $\bar{x}$ = 3.56, s = 1.56

20. I learned to be more empathetic and caring during my college years. $\bar{x}$ = 2.92, s = 1.28
21. I do not think it is necessary to be empathetic and caring if you want to be successful in the field of engineering. (Reverse coded for analysis) $\bar{x}$ = 4.75, s = 1.33
22. I do not think the engineering industry needs to be more empathetic/caring. (Reverse coded for analysis) $\bar{x}$ = 4.68, s = 1.29

23. Empathy and care is present in my work as engineer. $\bar{x}$ = 4.73, s = 1.05

Based on your engineering experiences in industry, to what extent do you agree or disagree with the following statements? Select from 1 to 6, considering 1 as ‘strongly disagree’ and 6 as ‘strongly agree’.

24. The concepts of empathy and care are well incorporated in my work. $\bar{x}$ = 4.31, s = 1.22

25. My bosses value employees that are empathetic and caring. $\bar{x}$ = 3.79, s = 1.35

26. My colleagues show empathy and care towards clients when s/he interacts with them. $\bar{x}$ = 4.20, s = 1.06

27. My colleagues show empathy and care when we work as a team. $\bar{x}$ = 4.27, s = 1.01

28. My profession involves the consideration of empathy and care. $\bar{x}$ = 4.02, s = 1.28
29. I am aware of policies on empathy and care at my work. $\bar{x}$ = 3.48, s = 1.66
30. I am aware of policies on empathy and care in my profession. $\bar{x}$ = 3.21, s = 1.53
31. I believe safety considerations involve caring. $\bar{x}$ = 4.68, s = 1.33

If empathy and care are effectively incorporated into engineering, to what extent do you think the following impacts will occur? From 1 to 6, considering 1 as ‘no impact’ and 6 as ‘very strong impact’.

32. Engineered products will fulfil users’ needs. $\bar{x}$ = 4.59, s = 1.19
33. Engineered products will be more environmentally friendly. $\bar{x}$ = 4.31, s = 1.28
34. There will be more mutual understanding, respect and trust between people involved. $\bar{x}$ = 4.75, s = 1.16
35. Engineered products will be more successful in the marketplace. $\bar{x}$ = 4.22, s = 1.29
36. Stakeholder considerations will become more central to engineering designs. $\bar{x}$ = 4.15, s = 1.30
37. Engineering will attract more females. $\bar{x}$ = 3.59, s = 1.

Upon completion of the survey, we invited participants to participate in a follow-up interview. Participants had the opportunity to provide additional comments at the end of the survey also.

Appendix 2. Pattern/structure matrices and communalities from principal component analysis with oblimin rotation with a delta of zero

	Pattern matrix					Structure matrix					
Item	1	2	3	4	5	1	2	3	4	5	Communalities
Q1	.10	.02	.08	**.68**	.03	.37	−.19	.36	.74	.11	.58
Q2	−.02	−.24	−.04	**.59**	.09	.24	−.36	.23	.63	.15	.45
Q3	.00	−.14	−.02	**.79**	.01	.30	−.32	.29	.82	.07	.69
Q4	−.05	−.12	−.01	**.80**	.02	.25	−.29	.29	.81	.08	.67
Q5	−.01	**−.78**	.13	.07	.01	.27	−.82	.34	.29	.10	.70
Q6	.04	**−.77**	.04	.13	−.07	.28	−.81	.27	.32	.02	.69
Q7	.04	−.22	.00	**.63**	−.07	.30	−.37	.28	.69	.00	.53
Q8	.01	**−.64**	−.01	.25	−.09	.24	−.69	.22	.39	−.01	.54
Q9	.08	.00	.26	.17	.08	.26	−.14	.37	.30	.14	.18
Q10	.09	**−.55**	.11	.19	.17	.37	−.66	.37	.40	.26	.56
Q11	.16	−.38	.01	.29	.33	.42	−.52	.31	.45	.41	.53
Q12	.04	**−.55**	.13	.20	.24	.35	−.66	.39	.41	.33	.59
Q17	.13	−.03	.31	.20	−.39	.27	−.15	.39	.33	−.31	.35
Q18	.11	.08	.13	.13	**.60**	.29	−.07	.28	.24	.64	.48
Q19	.28	−.05	.11	.08	**.53**	.46	−.21	.33	.26	.61	.52
Q20	.09	−.08	.24	−.10	**.50**	.26	−.18	.33	.07	.55	.39
Q21	.34	.18	.19	.31	−.15	.45	−.01	.37	.44	−.06	.36
Q22	.10	.13	.42	.28	−.18	.30	−.05	.50	.42	−.10	.37
Q23	**.53**	.07	.19	.19	−.02	.64	−.15	.45	.41	.10	.49
Q24	**.66**	−.03	.09	.11	−.03	.74	−.25	.40	.37	.11	.57
Q25	**.75**	.09	.00	.04	.11	.75	−.12	.30	.28	.23	.59
Q26	**.69**	.08	−.07	.12	.20	.71	−.13	.25	.32	.31	.56
Q27	**.63**	.11	.00	.12	.21	.68	−.10	.30	.32	.31	.52
Q28	**.67**	−.02	.08	.10	.12	.76	−.25	.40	.37	.25	.61
Q29	**.77**	−.22	−.07	−.21	−.09	.71	−.35	.21	.07	.04	.59
Q30	**.67**	−.34	−.01	−.27	−.07	.66	−.44	.24	.02	.06	.58
Q31	.35	−.39	.27	−.07	−.14	.51	−.52	.47	.22	−.01	.50
Q32	.03	−.07	**.74**	.02	−.03	.35	−.25	.77	.30	.08	.60
Q33	−.04	−.26	**.74**	−.10	.02	.30	−.41	.76	.21	.13	.65
Q34	.11	.13	**.66**	.13	.00	.39	−.09	.72	.37	.10	.55
Q35	.03	−.06	**.77**	−.02	.06	.36	−.26	.80	.28	.17	.65
Q36	.07	−.05	**.64**	.07	.15	.39	−.26	.73	.34	.26	.57
Q37	−.13	−.01	**.65**	−.13	.09	.10	−.11	.56	.06	.14	.36

Appendix 3. Inter-item bivariate correlation matrix (Pearson's *r*)

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q17	Q18	Q19	Q20	Q21	Q22	Q23	Q24	Q25	Q26	Q27	Q28	Q29	Q30	Q31	Q32	Q33	Q34	Q35	Q36	Q37
Q1	1	0.42	0.58	0.55	0.25	0.25	0.44	0.24	0.23	0.33	0.35	0.36	0.24	0.19	0.27	0.13	0.31	0.30	0.33	0.32	0.28	0.26	0.34	0.33	0.22	0.17	0.25	0.28	0.28	0.34	0.31	0.31	0.15
Q2		1	0.49	0.44	0.34	0.32	0.39	0.33	0.12	0.37	0.40	0.35	0.17	0.13	0.19	0.09	0.20	0.16	0.25	0.27	0.19	0.27	0.20	0.27	0.14	0.14	0.18	0.29	0.23	0.19	0.22	0.29	0.09
Q3			1	0.74	0.32	0.34	0.53	0.33	0.17	0.35	0.39	0.37	0.26	0.18	0.22	0.14	0.23	0.25	0.30	0.31	0.21	0.23	0.26	0.32	0.20	0.18	0.27	0.31	0.25	0.27	0.26	0.31	0.10
Q4				1	0.31	0.32	0.52	0.32	0.24	0.35	0.36	0.36	0.23	0.19	0.20	0.13	0.23	0.24	0.29	0.25	0.19	0.21	0.24	0.28	0.16	0.15	0.25	0.29	0.22	0.28	0.26	0.29	0.09
Q5					1	0.69	0.30	0.53	0.13	0.56	0.40	0.55	0.17	0.14	0.23	0.17	0.15	0.19	0.24	0.28	0.19	0.19	0.19	0.26	0.22	0.29	0.41	0.29	0.43	0.21	0.31	0.28	0.14
Q6						1	0.40	0.57	0.12	0.45	0.39	0.48	0.17	0.12	0.22	0.14	0.15	0.16	0.24	0.26	0.16	0.20	0.19	0.27	0.23	0.27	0.50	0.25	0.35	0.19	0.26	0.25	0.09
Q7							1	0.45	0.31	0.31	0.33	0.33	0.26	0.19	0.21	0.09	0.22	0.24	0.28	0.27	0.22	0.23	0.23	0.30	0.19	0.17	0.32	0.23	0.24	0.30	0.24	0.26	0.10
Q8								1	0.13	0.44	0.34	0.39	0.18	0.11	0.20	0.10	0.18	0.18	0.20	0.24	0.18	0.18	0.13	0.25	0.18	0.22	0.32	0.24	0.26	0.16	0.23	0.23	0.08
Q9									1	0.25	0.22	0.31	0.17	0.16	0.16	0.19	0.17	0.19	0.27	0.23	0.20	0.16	0.16	0.24	0.16	0.17	0.22	0.16	0.28	0.30	0.21	0.22	0.19
Q10										1	0.53	0.59	0.21	0.21	0.30	0.22	0.22	0.22	0.33	0.38	0.28	0.27	0.24	0.36	0.24	0.32	0.33	0.32	0.35	0.25	0.36	0.32	0.15
Q11											1	0.56	0.13	0.23	0.36	0.22	0.23	0.18	0.31	0.38	0.30	0.33	0.32	0.41	0.28	0.29	0.31	0.26	0.25	0.24	0.28	0.49	0.15
Q12												1	0.18	0.21	0.33	0.25	0.20	0.23	0.27	0.35	0.28	0.28	0.28	0.34	0.25	0.28	0.36	0.29	0.44	0.27	0.33	0.33	0.17
Q17													1	0.01	0.05	0.13	0.16	0.20	0.26	0.29	0.15	0.16	0.15	0.18	0.11	0.13	0.23	0.25	0.26	0.27	0.21	0.20	0.18
Q18														1	0.44	0.28	0.17	0.18	0.27	0.23	0.26	0.22	0.22	0.31	0.16	0.16	0.18	0.19	0.23	0.25	0.23	0.22	0.11
Q19															1	0.33	0.26	0.21	0.35	0.35	0.32	0.34	0.31	0.40	0.28	0.28	0.28	0.27	0.23	0.27	0.30	0.32	0.13
Q20																1	0.08	0.11	0.18	0.20	0.21	0.22	0.24	0.23	0.19	0.24	0.18	0.20	0.26	0.20	0.23	0.23	0.20
Q21																	1	0.51	0.35	0.31	0.29	0.25	0.24	0.34	0.20	0.16	0.23	0.27	0.16	0.29	0.26	0.26	0.08
Q22																		1	0.30	0.27	0.19	0.15	0.14	0.25	0.12	0.12	0.23	0.29	0.28	0.37	0.30	0.29	0.16
Q23																			1	0.60	0.42	0.40	0.36	0.50	0.31	0.28	0.35	0.34	0.31	0.37	0.33	0.36	0.15
Q24																				1	0.55	0.46	0.40	0.55	0.39	0.37	0.38	0.32	0.29	0.32	0.34	0.37	0.12
Q25																					1	0.56	0.53	0.53	0.42	0.33	0.30	0.28	0.25	0.31	0.29	0.28	0.11
Q26																						1	0.67	0.51	0.32	0.28	0.30	0.25	0.21	0.27	0.25	0.31	0.10
Q27																							1	0.49	0.33	0.28	0.31	0.27	0.26	0.31	0.28	0.32	0.13
Q28																								1	0.44	0.44	0.39	0.35	0.30	0.35	0.39	0.41	0.12
Q29																									1	0.75	0.36	0.22	0.21	0.20	0.22	0.24	0.11
Q30																										1	0.38	0.23	0.25	0.19	0.23	0.26	0.14
Q31																											1	0.37	0.42	0.31	0.36	0.34	0.19
Q32																												1	0.60	0.46	0.65	0.57	0.27
Q33																													1	0.47	0.56	0.47	0.34
Q34																														1	0.51	0.46	0.30
Q35																															1	0.62	0.34
Q36																																1	0.36
Q37																																	1

Appendix 4. Inter-factor bivariate correlations (Pearson's *r*)

	F1	F2	F3	F4	F5
Factor 1: Current existence	1	0.459	0.473	0.444	0.482
Factor 2: Perceived importance		1	0.443	0.531	0.340
Factor 3: Potential benefits			1	0.412	0.403
Factor 4: Relational value				1	0.291
Factor 5: Learnability					1