Empathy, persuasiveness and knowledge promote innovative engineering and entrepreneurial skills

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\textbf{ABSTRACT}

An increasing number of experts considers that durable skills are needed to prepare the professionals that will tackle the challenges of the 21\textsuperscript{st} century. However, a clear overview of which skills are the most relevant for specific learning outcomes has not been reached. In this work, we present a simplified conceptual framework for the training of engineers to be more innovative and entrepreneurial. We introduce three core components or ingredients: knowledge, persuasiveness and empathy. These ingredients can be used to initiate a necessary shift in how students are educated in fields of science, technology, engineering, and mathematics. A Challenge Based Learning context is proposed for developing persuasiveness and empathy as durable skills. We also present a six-step procedure as a guideline to turn the knowledge, persuasiveness, and empathy framework into actionable items. This framework enriches the toolbox of durable skills that needs to be taught during the educational process, and in the professional practice of (chemical) engineers. We propose to explicitly teach the importance of durable people-oriented skills in combination with technical courses, ideally spreading the focus over the whole curricula.

1. Introduction

Engineers need a balanced set of skills, from technical to the so-called ‘soft’ or people-related ones, for interdisciplinary teamwork, (Balles-teros et al., 2021; Backlund and Sjunnesson, 2012). These interpersonal skills have more recently been termed ‘durable skills’, since they should last a lifetime (Kamp, 2019,2020). Other transferrable skills such as critical mindset, interdisciplinary collaboration, communication, and information literacy are listed among the “21\textsuperscript{st} Century Skills” given by Ananiadou and Claro (2009). Moreover, there is growing demand for professionals with entrepreneurial and innovative thinking at the undergraduate and postgraduate levels. Both trends emerge from the urgent challenges faced to address complex and global sustainability problems of today, Jamieson et al. (2021).

However, the means to teach innovation, entrepreneurial aspects and durable skills are often spread over different and specialised fields. Consequently, it often takes a long time for the education professionals to apply them in the current teaching and training curricula. Therefore, we see great value in having a simple, universal framework that can be understood by the students, professionals and the teachers who face increased demand for fast changing requirements.

The ongoing Covid-19 pandemic has affected the way we teach, in particular the practical work in labs and student-group activities, but also industry-linked activities, such as visits to plants Kavanagh (2021). Fortunately, there was already an ongoing trend that led to the availability of mature methods to teach with the support of online tools, such as recorded lectures, interactive multimedia, and remote video conferences prevented a total halt of educational efforts worldwide. But these can only take us so far. How could we fill the gap between the conventional engineering education, —which is now severely affected by isolated and passive teaching-learning process imposed during pandemics—, and a more durable and meaningful personal and professional development journey?

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We propose to fill the educational gap by focusing on three ingredients, Knowledge, Persuasiveness, and Empathy (KPE), where the stress is on developing human aspects and skills that are more \textit{durable} than any single technological skill. Developing these skills properly do not depend strongly on the access to specific equipment, or the proximity to any plant or industrial scenario. They can be nurtured individually or in groups, with or without the support from teachers or coaches, fulfilling demands for life-long and self-education beyond the university walls.

Fig. 1 provides a visualization of the interaction of the ingredients in the KPE framework. In the $z$-axis (in plane), different disciplines or fields can be assigned. No borders are defined since the fields of engineering and innovation deal with multidisciplinary problems.

In the following sections, we will present concepts we have distilled into the KPE framework from a combination of literature research and our professional experience. To make the concepts of the KPE framework more tangible to students, we propose an experiential approach and a six-step guide for the students in Challenge Based Learning settings. The Annexes provide useful information for the teachers and experts interested in seeing how we are implementing our ideas in the classroom. This framework can be used by problem-solvers of any background to innovate in a clear, step-by-step manner, but the examples we provide come from the ac Chemical Engineering field.

We begin with why innovation and entrepreneurship needs to be taught through the lens of KPE and our definitions of concepts used in this work.

2. The need for teaching innovation and entrepreneurship

The necessity to innovate permeates most sectors of human activity, including education. This need arises from the rapid globalization of nearly all human activities in this past century, where we are arguably reaching resource limitations in numerous sectors of our economies, and must consider continued impacts on the environment and human health. To maintain our standards of living and optimistic expectations of the future, we must undergo a paradigm shift in how we can societally embed principles of sustainability, and as a crucial component of that, we must develop social network competences in order to innovate (García-Martínez, 2021; Garcia-Martínez et al., 2020). The ability of engineers and innovators to adapt, or of a startup to be agile while navigating a market landscape, is also often discussed in the context of creating successful startups (Müller and Thoring, 2012). To pivot successfully, Eesley and Wu (2019) demonstrated the importance of having a mentor who provides access to a structurally diverse social network. The experiential and mentoring elements tie in with the ability to develop relationships, which is partially built upon KPE. We expand further in the next section.

2.1. Who is entrepreneur?

For the purpose of examining the impact of \textit{knowledge, persuasiveness, and empathy}, we define \textit{entrepreneurs as risk takers}, and accept the basic premises of the risk-bearing theory of profit laid out by Hawley (1907) and others noted in the summary of Gedeon (2014). However, we define the risks taken to include the time of the individual in addition to the resources expended in their attempt to change a product, method, practice, or way of thinking.

Generally, this risk is leveraged to “change the yield of resources”, as stated by Say (1816) where this yield may return a profit for the risk-taker, although there are many other non-profit-oriented goals an entrepreneur may hold. Specifically, an entrepreneur is taking a chance or risk in between people or processes—this is according to Knight (1921) and Drucker (1998), whose views are linked to Schumpeter’s, where entrepreneurs are individuals who “exploit market opportunities” and “whose function it is to carry out new combinations” Schumpeter (2013).

There are many other ways to define what an entrepreneur is or what they do, (Bylund, 2020; Gedeon, 2010; Thomas and Mueller, 2000) since categorization can come from sociocultural and economic factors, such as social entrepreneurs, (Godschall et al., 2021; Méndez-Picazo et al., 2020), or the Maker Movement, (Giusti et al., 2020), Malerba and McKelvey (2020) state that entrepreneurs turn technology and ideas into innovations in the market, creating opportunities, by both driving and adapting to change in the external environment.

2.2. Defining knowledge, \textit{K}

For this article, \textit{Knowledge is information connected to a specific problem, and aligned towards a possible solution}. It may state a
what, why, when, and/or how of something related to the problem, and also who and where.

We make a distinction between information and knowledge. Among several attempts to differentiate between them, we find the pyramidal representation of the relationship between data, information, knowledge, and wisdom (Wikipedia, 2022). Information is generally more easily acquired than knowledge. A non-exhaustive list of examples includes information gathering by reading material from a library or from internet searches, asking an expert, or from personal experiences.

For the information to become knowledge that relates to a problem, an individual must apply cognitive processing, Krch (2011). Knowledge is created as a bundle of heterogeneous but complimentary resources with three core types: explicit (documented information), implicit (applied information), and tacit (understood information). This interesting topic is still debated and redefined Bolade (2021).

In all cases, different types of information allows building knowledge about almost anything. With the right discipline and quality assurance in the process of acquiring knowledge, this is a way with which people can become experts in one field.

Another significant element is related to practicing expert-like decision making, to develop a mental framework in the discipline of choice. These are summarised in the Pillars of Deliberate Practice, (Ericsson et al., 1993; Melrose, 2022) or as put by Ericsson and Pool (2016): expertise can be learned with challenging but doable tasks, practicing elements of expertise with feedback and reflection slides. Thus, instructors should develop activities aimed at demanding substantial focus and effort from the students, instead of passive listening to a lecture or performing easy tasks Wieman (2012). These steps are necessary to synthesize or develop knowledge, transfer it to a different context, or enrich it with tacit knowledge in order to address a problem or advance a field.

We provide a question and answer examples about how we are teaching this concept in a MSc course at the University of Twente in Annex 1c 2, and expand in Section 3.1.

2.3. Defining persuasiveness, P

Throughout this article, Persuasiveness is used in the context of convincing others that a problem one is trying to solve is important, or that a given solution is the right approach to solve it.

In Science, Technology, Engineering, and Mathematics (STEM) curricula, there is often an emphasis on mastering technical ability, with an assumption that personal and interpersonal skills such as communication, team work, time management, emotional intelligence, decision-making, and the like will develop as learners complete curriculum requirements. As mentioned in the Introduction, ‘soft skills’ may better be labeled as durable skills (Kamp, 2019,2020), since they will last a lifetime, as opposed to some areas of technical knowledge learned during degree courses which can often have a short shelf-life as technologies rapidly advance.

We generalize our definition of Persuasiveness to the ability to transfer understanding of a showcased perspective or idea, resulting in agreement between the persuader and persuadee. This is a key ability for developing relationships between peoples, of relevance for engineers and innovators.

Most societally-relevant problems tend to be complex, and demand multidisciplinary teams to co-create knowledge, Ruoslahti (2020). This directly pertains to persuasiveness. For example, when requesting funds for a research idea, persuading investors or subsidy committees. To do so effectively, enlisting the assistance of experts or colleagues to sharpen your skills at persuading by reviewing your proposal, developing a perfect pitch, and recruiting team members.

Schumpeter (1982) said that “The innovator-entrepreneur must convince the capitalist that the higher revenues and/or lower costs stemming from his innovation will enable him to pay both principal and interest on the loan. The innovator must convince himself that the profits expected from the innovation will be sufficient to do this and leave a net profit for him.

This ability is typically acquired through interaction with people, and interacting with passive information—you must acquire the information, process it, act upon it, then reflect and adjust future actions according to what did or did not work.

We provide examples of questions and answers about how we are teaching this concept in a MSc course at the University of Twente in Annex 1c 2, and expand in Section 3.1.

2.4. Defining empathy, E

We define empathy as the ability to understand or accurately predict the perspectives of others. From that understanding, we can identify their needs and desires, then decide to act on them. We could label it as actionable empathy. Among the different forms of empathy, (Hodges et al., 2007; Kopajtic, 2020), we have:

- Cognitive empathy: how well an individual can perceive and understand the emotions of another.
- Affective empathy: expressing an understanding of how and why the other person feels in a certain way.
- Emotional empathy: According to Hodges and Myers, it consists of three components. “The first is feeling the same emotion as another person...The second component, personal distress, refers to one’s own feelings of distress in response to perceiving another’s plight... The third emotional component, feeling compassion for another person, is the one most frequently associated with the study of empathy in psychology”.
- Behavioral empathy: a demonstration of active listening, with expressing a desire to understand more about the others’ feelings, experiences, or reactions, Clark et al. (2019).
- Contagion empathy: characterised by relative passivity to the emotions of others.
- Projection empathy: characterised by active engagement with the emotions of another.

Projection empathy is similar to our Actionable empathy, because it is capable of producing greater understanding about other people or impact of the problem. Based on a recent book review (Kopajtic, 2020; Pleischacker, 2019), we interpret that a combination of projection and contagion is desirable for STEM students. Contagion empathy provides raw materials needed in imaginative and projective exercises and compensate the difficulty to have direct access to the emotions of others.

STEM professionals who can empathise or have the ability to place themselves into an imaginary situation and somehow feel those emotions, or at least imagine them, should be able to better understand the context of a problem. Pursuing an empathic approach can help to develop the ability of the engineer to formulate each problem succinctly and effectively, assisting in understanding the ‘why’ of the need to solve the problem. We also believe we should be able to expand our Empathy beyond other fellow humans – currently living and future generations – and consider also living organisms.

Definitions of sympathy occasionally overlap with those of emotional empathy. For our purposes however, we define sympathy as: a temporary, emotional response coupled with an expression of that emotion toward the other individual, e.g., pitying the individual and offering condolences. With sympathy, the emotion felt and expressed do not necessarily reflect the emotional state of the person to whom the reaction is occurring.

We provide examples of student’s online discussions, assignments and answers provided by the students as we teach this concept in a MSc course at the University of Twente in Annex 1 a, b, and Annex 2.
3. The need for teaching durable skills in engineering

It is possible that engineers acquire durable skills without formal training, or have them intrinsically due to personality and unique experiences. In contrast with other curricula, engineering students may require wide but not so deep knowledge on a specific discipline, as long as they are willing to learn in the process or incorporate other team members that do possess it. The education of Chemical Engineers is arguably one of the most general activities, and we strongly believe there is still space for durable skills in the context of KPE in the curricula Fernandez Rivas (2022).

STEM careers are traditionally focused on providing as much knowledge as possible, typically oriented to specific skills such as solving differential equations, designing, or computer modelling, to name a few. What to do with all that knowledge and how to communicate it to the stakeholders is a challenge that is often underestimated. Moreover, clear indications or practical guides to transfer inventions from the university environment to the market are rarely given, Lunnuzzi (2017). We believe that clarifying the impact of engineering work and its relevance to society can be reached by teaching empathy among other durable skills.

An empathy-centered program would emphasize making real-world impact. Kamp (2020) recently argued that human literacy is about empathy, communication, and the ability to connect people by putting relationships at the heart of the work. These qualities are gaining a critical role in the STEM field, with the term “STEMpathy” being popularized by Friedman (2017).

Friedman argues that technological-and-knowledge-based capacity in STEM must be coupled with empathy for other human beings since, “Nobody cares what you know, because the Google machine knows everything”; instead, Friedman stresses that the future is about how we apply what we know. In the view of Kamp (2020), there will be more emphasis on engineering as a social activity and empathy with customers and colleagues, together with concepts of autonomy, agency, self-efficacy and emotional intelligence to function in the human milieu.

In the rare instances where durable skills are explicitly taught, some may instruct directly about Persuasiveness. This is a skill typically associated with what may be taught at business schools, related to everything; instead, Friedman stresses that the future is about how we apply what we know. In the view of Kamp (2020), there will be more emphasis on engineering as a social activity and empathy with customers and colleagues, together with concepts of autonomy, agency, self-efficacy and emotional intelligence to function in the human milieu.

In the rare instances where durable skills are explicitly taught, some may instruct directly about Persuasiveness. This is a skill typically associated with what may be taught at business schools, related to company creation, market forces, communication and negotiations, Feder (2021). Kamp (2016) and Felder (2018) posit that to learn in a meaningful manner, students must be actively engaged in the learning process. Kamp (2016) points out that it is not only a matter of engagement, but also of serious reflection on what the students have learned and experienced.

In this line, professional education experts are increasingly showing the importance of empathy. There have been attempts to measure empathy from instructors for their students, using open-ended responses as stimulated experimental situations (Tettegah and Anderson, 2007; Arghode et al., 2013). Similarly, a point has been made in designing learning activities to support the skills of professional practice and social responsibility Jamieson et al. (2021). These activities should include contextual and situational elements that provide students with experience and the chance to apply specialised knowledge.

Performing social and analytic cognitive tasks simultaneously has been found to be difficult: “brains cannot analyze and empathize at the same time” Walther et al. (2020). The authors recognised that Empathy is increasingly acknowledged as important and implicitly present in both educational and industry. Moreover, practicing empathy seems to generate some tensions in both domains. Cech (2014) identified a “culture of disengagement” in engineering education, seemingly related to attempts of removing politics, or any “non-technical” concerns, e.g., public welfare. These ideas will be expanded in the next section.

There are a few ways that teachers can transfer durable skills: .

- Direct instruction on KPE
- Implementing KPE in the whole curriculum e.g. in a learning line of academic skills

Whatever the chosen activities, we think that it is beneficial for the teaching team to be implicit and explicit when working with KPE, at the individual and group levels. Our reasoning is rooted in the experiences we have as teachers, the advice from educational experts and literature we consulted regarding this aspect Walther et al. (2020).

3.1. Teaching persuasiveness

The challenge of teaching persuasiveness as a “durable skill” increases with the degree of “softness”. Traditionally, gained knowledge and skills can be demonstrated via exams or tests, e.g., successfully completing a simulation training with a software, the student is able to discuss or write about a theoretical or abstract concept. Business schools are probably the place most people would look when interested in gaining decision-making skills, time management, etc. We use this simple example for students: Knowledge taken from a book; Persuasiveness skills gained through experiential practices with cases from real life in the university-academic settings; Empathy acquired during an internship or bachelor assignment inserted in a company. For other examples on how we have been teaching about KPE, please see Annex 1.

The Persuasiveness assignment in Annex 1c has undergone testing from a pedagogical perspective through discussions in class and with colleagues, see Annex 2. Outcomes from this lead us to conclude the simplest way to teach persuasiveness is to provide cases, both, imaginary and real, in line with CBL, see Section 4.2.

As stated in the Syllabus of the course being taught at the University of Twente, see Annex 1a, we follow a process that simulates a real-life scenario that can be found in academic settings or the business world. We include three basic elements:

1. In-depth knowledge of an emerging field of research and current industrial relevance

Gaining information that should become knowledge valid for the final test or team-work, and there is a mix of individual and work in teams. We use Process Intensification as innovation template (Fernandez Rivas et al., 2020; Rivas et al., 2020).

2. Work in teams

The teams are presented then with an open problem provided from real-life, taken from the instructors’ industrial or academic network.

3. Appropriate professionalisation component

After completing steps one and two, the students go out on their own to complement or expand their knowledge and propose a solution. The solution is then written in a report, and later discussed in a presentation in front of the “case owners”, as if trying to convince them, or persuade them that their solution makes sense.

Once students have been provided the KPE framework that guides their thinking and approach, there are many paths they can take to practically apply it. In all cases, however, decisions will have to be made. Decision-making is a complex process, and often the interaction or comparison of factors influencing the decision is unclear. This is certainly the case in CBL, where clearly-defined impact on outcomes from one factor versus another are often difficult to establish.

To help students increase their Persuasiveness skills and familiarise with decision making exercises, we are teaching an in-house developed concept in MSc courses at the University of Twente, see Annex 3. The Intensification Factor (IF) method, (Rivas et al., 2018; Rivas and Cintas, 2022), is a tool to provide arguments in persuading other stakeholders and consider other “people-oriented factors”. In this context, the students can compare and demonstrate superiority of ideas. Moreover, such a simple method can be seen as a tool for implementing personalised feedback. For example, when the result of an IF
exercise calculated by the student differs from the answer expected by the instructor, the student can expose the reasoning in a transparent way. Tools like this can act as a ‘stage-gate’ in the student understanding (Beneroso and Robinson, 2021).

Our teaching assistants and teachers regularly meet with the group of students and show during lectures or individual team-meetings, how to approach problems with analogies to the student’s project.

Three main aspects are emphasized:

1. Simplicity of the solution and how well it is explained. Peer-review round is a common method to assess simplicity and explanation clarity; see Annex 1a. Peer-led assessment works particularly well in this method, as the students are given similar contexts and frameworks, but different challenges to work on. This approach of project-led education has been identified as an efficient active learning method, and instrumental to learning to “understand” Alink and van den Berg (2013). Having different projects with the same instructions and different problem (chosen by the students) and the same starting point (knowledge acquisition), students can give feedback to polish their idea. For some examples, see Annex 1a)

2. Solution validation by stakeholders. It can be in the form of an interview, or statements from a reliable source, such as an interview or scientific publication. The case owner can also help assessing the findings.

3. Feasibility of the proposed action plan that leads to the execution of the problem’s solution.

This is definitely the hardest, because our courses are not sufficiently long to allow for executing their proposed solution and validate if it is feasible. The preparation to face milestones or expectations not reached is another explicit focus of Challenge Based Learning (CBL), a source of frustration for many students.

3.2. Teaching empathy

To succeed in having the much needed paradigm shift towards sustainability mentioned in the Introduction, we need to equip future generations of engineers to master an empathic approach to work. This has been identified as a vital aspect, not only for human-human interactions, e.g. health professionals, (Pedersen, 2010; Jeffreys and Downie, 2016), but for training machines to interact with humans, (Jeffreys, 2018; Liu and Sundar, 2018). The challenges and controversies of teaching empathy have been discussed in ethics, social science, history, medical and legal training, (Gribble and Oliver, 1973; Jeffreys and Downie, 2016; Westaby and Jones, 2018). Attempts to conceptually and empirically distinguish among various types of emotional responses and measure its relation to empathy have been done through physiological, facial indexes, and self-report indexes, (Mehrabian and Epstein, 1972; Eisenberg and Fabs, 1990). In the case of humans, it seems that it can be developed as an emotional intelligence through receiving examples and providing role models. See Annexes 1a, 1b and 2, for examples used in our teaching and testimonials.

In another professional field, design thinkers learn to observe, interview, and develop empathetic insights with the aim to find human-centered ways of solving problems, Carroll (2015). When working with other people, Backlund and Sjunnesson (2012) they stated “you know what they feel, you feel what they think. That is empathy, the first half of cooperation. The second half is the ability to reconsider your own thinking: self-criticism.” These abilities, to ‘feel’ and ‘rethink your own standpoint’, are needed for effective cooperation, and is a human ability.

Recent studies state that experiencing empathy in an engineering context, followed by reflecting on such experiences allowed for students to gain awareness with fundamental aspects regarding their professional formation (Walther et al., 2020). The authors found that when students engage in empathy activities they have experiences that teach them to appreciate the significance of both ‘skills and values orientations’ and to frame ‘their orientations toward others and their self-understanding as engineers’. The development of empathy is proposed to be an integral core of being an engineer in the 21st century, together with ethics, communication and stakeholder interaction. Empathy enables students to gain understanding of their own interaction with others and inter-personal relationships, clarifying their place as an individual and professional in the world.

Arguably, students need to learn to make highly-educated guesses in the face of uncertainty. To train under uncertain conditions, engineering educators have implemented learning from social work to inform the education of empathic engineers, that led to a teachable model of empathy in engineering with ‘learnable skills, a practice orientation, and a professional way of being.’ Walther et al. (2017). This conceptual model tries to mitigate potential consequences correlated to the deteriorating concern of engineering students for public welfare along their education (Czech, 2014).

In the context of engineering projects, empathy can be utilized:

1. To identify a problem affecting others that represents an opportunity for solution creation.

   the engineer must additionally understand what has been done before, why the current method or product is lacking for those currently using it, and create in a way to address that lack. The development of this understanding typically requires interaction with other people. When humans interact, there are several emotions or transactional activities that are relevant in most professional fields.

2. To create a compelling case, either to convince others of the importance of a problem or the impact of a potential solution.

   Professionals interfacing with other team members, customers, or patients, must connect to their experiences for effective communication. However, there are boundaries for this type of connection that impact the solution the professional can provide. For example, healthcare professionals are trained to distinguish between sympathy and empathy, and taught to be empathetic and not sympathetic, as sympathy will hinder appropriate diagnosis.

   We reason that sympathy is not appropriate for a professional working as an innovator either, as it is brief in nature and does not necessarily provide an accurate picture of how a problem impacts people. To succeed in valorising an innovative idea, cognitive empathy (defined above) may not be sufficient either, since the detached tone associated with it does not help in the important action of Persuasion.

3.3. When to teach P and E

   Our KPE framework enriches the small number of conceptual models and empirical bases that permits integrating empathy into the discussion and practices of engineering education (Strobel et al., 2013). A gradual shift towards teaching durable skills along the curricula can be made using existing courses or specific moments where students can be trained in such situational or context-related role plays. In some countries, capstone programs/projects can be an ideal moment to let students interact with other students or real stakeholders of a given problem. Student teams develop novel engineering project ideas, which in some cases can be sold or developed with support from stakeholders. These projects can be executed over a semester or over an academic year, which allows for a true training in professional aspects and maturing ideas and internalising what an ‘engineer can do’. This maturing process is accompanied by reassessments and alterations to the initial project ideas.

   The role of empathy in engineering education has been demonstrated to make the value orientations of students and their relationships toward others pedagogically accessible, Walther et al. (2020). The authors highlight that the student’s self-understanding as engineers can provide new avenues “for research and education to engage less tangible facets
of ‘engineering formation.’ The results were drawn from reflections written during empathy modules in an Engineering and Society course. The students participated in role-play situations, e.g., a student was an engineer addressing the concerns of a single father facing an increase in utility expenses as part of remediation efforts around the Flint water crisis. We will continue updating our activities, particularly student reflections, and identify which of them lead to a better learning process.

4. The KPE framework and redefining the engineer

Based on traditional education practices, a common starting point when engaging in problem-solving is knowledge. However, as Perez-Brevia (2016) says, it is not necessary to be an expert at the problem you are trying to solve from the beginning—rather, you learn in the process and you therefore can start with just a piece of knowledge. Furthermore, the three ingredients of Knowledge, Persuasiveness, and Empathy are not linear or static concepts; they are entwined, see Fig. 1. For example, the ability to persuade is often predicated on connecting with those being persuaded; namely, empathising with them. And as one empathizes, one may gain more knowledge first-hand about the problem faced. This can then become an iterative process.

These are not the only ingredients necessary to successfully educate learners to become innovators. For example, the ability to develop (social) relationships is often key for innovators and entrepreneurs. This ability is reliant on inspiring trust, being sociable, and may sometimes require humility. However, one can readily link these characteristics to knowledge, persuasiveness, and empathy, which at the least are used to enhance the ability of developing relationships.

4.1. An engineer is ...

If we accept the need to train students to face future challenges, we propose updating the definition of what an Engineer is (Fig. 2).

There are plenty of examples of what engineers are capable of, and there is abundant literature on skills that engineers need. Engineers are expected to apply scientific knowledge to solve technical and technological problems underpinned by creativity and practice. Interestingly, engineers are often seen as good in understanding policy and organisational aspects related to technology Fernandez Rivas (2022).

Other experts have already indicated that Chemical Engineering is in need of a more entrepreneurial or risk-taking attitude, and the importance of research commercialization (Martinez, 2022; Garcia-Martinez, 2021). Empathy has been highlighted for the social, cultural, and life cycle impacts of the solutions proposed by engineers. There are three frameworks for the design of engineering program learning activities and experiences, aimed at achieving attributes in line with the emerging sustainability culture: (1) the CEAB Graduate Attribute framework (Resources, 2022), (2) the United Nations (UN) Sustainable development framework (UN Sustainable Development Summit, 2022), and (3) the Risk Based Process Safety (RBPS) management framework (AIChE CCPS, 2022).

In this line, a roadmap for the advancement of chemistry: Sustainability, Innovation, Diversity and Education (SIDE) summarises recommendations from various organizations and initiatives, of which we highlight:

- Sustainability: Design for reuse, Conduct full life-cycle analysis, Use catalysts to improve efficiency, Reduce use of solvents.
- Innovation: Set strategic goals and clear priorities, promote Entrepreneurship, promote sharing of knowledge, Make use of open innovation and Empower your team.
- Diversity: Lead by example, Support marginalised scientists/employees, Be aware of unconscious bias, Recognise those with less visibility
- Education: Teach in context, Adopt systems thinking, Integrate SDGs in the curriculum, Promote question-driven education, Promote student-centred learning, Educate for complexity and uncertainty.

These recommendations should assist in solving the interconnected challenges we are facing. However, a more exact or universal definition of what an Engineer is elusive, because each country or discipline has its own take on the matter.

4.1.1. KPE-engineering

The following is an example for the students to see the alignment between a hypothetical situation, the KPE and the Engineer definition.

1. K: You came up with a (brilliant, ingenious) idea or solution for a problem.
2. P: You have the opportunity to pitch your plan or idea at a Dragons’ Den.
3. E: You prepare for when you pitch in way you could persuade a stakeholder or a section of society, and in that way he should be able to connect technical advances to useful applications to solve the stakeholder’s. We use several examples to clarify the concept of stakeholder and the importance of aligning interests and manage expectations. “Academia is often focused on pushing the boundaries forward through proof-of-concept demonstrations, while corporates may be looking for something incremental that can align to existing offerings, mature development processes or sales motions. And in between are start-ups coming from universities that are in the process of establishing product-market fit.” Jambunathan (2022).

- Connector: Empathy allows the engineer to identify the needs of a stakeholder or a section of society, and in that way he should be able to connect technical advances to useful applications to solve the stakeholder’s. We use several examples to clarify the concept of stakeholder and the importance of aligning interests and manage expectations. “Academia is often focused on pushing the boundaries forward through proof-of-concept demonstrations, while corporates may be looking for something incremental that can align to existing offerings, mature development processes or sales motions. And in between are start-ups coming from universities that are in the process of establishing product-market fit.” Jambunathan (2022).

- Ingenious: The ingenuity, which corresponds to the quality of being clever, original, and inventive, can be related to naive approaches which can help finding information and transforming it into knowledge. This knowledge can be used to find solutions where a serious or established approaches might not work. One example we teach our students is related to ‘Defamiliarization’, in which usual things are framed in a different way (Epstein, 2021). Such approach can help students to identify ‘taken-for-granted’ technologies, account for ethnography and the role of information and communication technologies (Bell and Others, 2005). In simpler words, we can speak about redefining the problem or being prepared to address new problems. One example of a seemingly simplistic approach is the carbonated water assignment in Annex 1c, providing an idea that was not explored for decades of scientific and technological progress in ultrasonic sonochemistry (i.e. chemistry caused by sound phenomena).

- Teacher: We stress in classes that students can learn a lot while teaching others, and it helps us also clarifying further the elements discussed in the course. A good teacher can persuade those at the...
receiving end to improve their understanding and take action towards the solution of a problem. Persuasiveness can be seen as a positive interpersonal trait, whereas ingenuity is more of a personal trait. Having the right ingenuity can assist teaching facts and ways of working to other people, and the student during a reflection exercise.

Annex 5 shows an example about the Changing ratio of K, P, and E importance in a generic innovation experience.

4.2. Challenging learning and education

We identify CBL as an effective way to teach and ensure better learning experiences (Fernandez Rivas et al., 2020). There, we proposed a visualization of how to combine Bloom’s Taxonomy Bloom (1956) with the “Chemical Engineering Toolbox” required in Process Intensification and aligned with the UN Sustainable Development Goals. In CBL, students need to be actively engaged in a challenging problem with elements of real-world context, which typically are open problems (open-ended, unstructured, interdisciplinary, etc.) without known solutions.

In short, CBL can be split into (1) Engage, where students get connected to the problem and define the actual problem they will work on with the help of a tutor and interacting with peers, (2) Investigate, where they find new knowledge and skills to understand and analyse the problem mainly during self-study, and (3) Act, where students design, implement and evaluate a solution, ideally with input from real-life stakeholders.

The addition of challenges to learning environments results in passion, ownership, and training which more readily reflects the processes in the real world. The ingredients Empathy and Persuasiveness are readily incorporated into these three steps, stemming from the enhanced passion and ownership of the challenge faced. There is a crucial relationship between empathy in learning and motivation (encompassing growth-mindset, self-efficacy), and it has been highlighted at different levels of education, Cooper (2011). Additional learning outcomes potentially necessary for the innovative process not encompassed by KPE include traits such as courage, risk-taking, and the ability to cope with uncertainty. As discussed previously, KPE provides an educational, foundational framework to attain more cognitively complex attributes.

Lastly, three important elements need to accompany CBL and KPE: documentation, sharing and reflection of each of these steps. Without them, the actual process can be lost or will be difficult to use in the future. The evidence or reasoning behind every decision can help persuade others or inform at least when and what influenced each aspect. In a way, the self-learning sought by CBL is what we believe correspond to self-discovery of solutions to problems, but perhaps in more realistic settings (outside the classroom).

5. KPE and a guide to solve problems

Most STEM students find it interesting to conceptualise ideas in the form of equations, which we gladly teach. To provide a semiquantitative analysis based on KPE to create innovative solutions, S, we propose to identify Other Factors (OF) which can impact the applicability (A) of a given solution at a given time (t). Therefore,

\[ A(t) = S(K(t), P(t), E(t)) - OF(t) \]  

(1)

where there can be a time dependence on each of the ingredients as well.

The students are then instructed to aim at maximising the value of A by increasing K, P and E to the level needed, and identifying OF that may stand in their way. We connect the OF to Intensification Factors (IF), from the IF Method, explained in Annex 3 and expanded in (Rivas et al., 2018; Rivas and Cintas, 2022).

Specifically, the importance of each ingredient relative to each other may vary dependent upon what stage of the project or innovation process one is at. To tackle engineering innovations, we propose following six steps, see Fig. 3. The levels of KPE at each step are indicative and should be taken as relative to each other.

1. **Defining the magnitude of the problem.** We assume at this stage that Knowledge is likely the most important of the three ingredients. Clearly defining the total number of people impacted, identifying the most impacted subgroups, obtaining a monetary estimate of the impact, identifying additional (non-monetary) problems that the main problem can lead to, and understanding the context. Here, the PESTEL N.A. (2022) particularly reflections, framework is useful, though additional factors such as Demographics, Intercultural, Ethical and Ecological can also be added. Empathy might have some use at this initial stage in fully defining the extent of impact a problem has on some people, but it may also cause one to focus too much on a subgroup of people.

2. **Devise a first solution, define milestones, reflect on limitations.** Subdivide the process of creating a first-attempt solution into achievable milestones. Plan steps that will allow incremental achievements towards creating a comprehensive solution, while simultaneously budgeting time and resources for reflection, analysis, and feedback to incorporate changes and adapt as new information is obtained. Clearly define the limitations of each step to attempt to predict what you might not know at a certain stage; doing so comprehensively will not be possible without extensive prior experience, but adopting a strategy that allows for re-evaluation lowers the risk of missing information that can significantly change the direction one is going. Clearly define a ‘go-no go’ step or time period. During this step, one should evaluate the time and resources one has at their disposal to continue going and weigh these against the probability of success (or risk of failure). If possible, establish contingency plans if there are several “go” or “no go” options that can salvage part of the achievements made up to that point. A “no go” does not have to mean a hard stop of the work done so far, but may indicate that a pivot towards a new end-goal is necessary. At this stage, knowledge (in conjunction with continuous information gathering) is still likely the most important out of KPE, but empathy will begin to play a larger role when defining go vs. no-go scenarios, particularly when working in a team where you are now risking the time and resources of others in an entrepreneurial pursuit vs. the market demands and group for whom you are developing a solution.

3. **Define metrics.** Select what aspects are important to reach each milestone. The selection allows for focus and makes it clear what information is needed most urgently. Most importantly, define several metrics or factors that can be used to evaluate whether the problem was mitigated by a solution; these factors can be defined even without a specific solution already developed. These factors can be used to define a before and an after the introduction of a solution. The process to approximate a quantification for this evaluation is explained in Annex 3 and expanded in (Rivas et al., 2018; Rivas and Cintas, 2022), termed the IF Method.
6. **Selected evidence of application of KPE**

We first provide a list of the Annexes cited in the previous sections, which contain evidence of our experiences teaching KPE.

- **Annex 1**
  1. [a] Fall 2021: Course syllabus, Discussion on ‘What is Empathy?’, ‘Empathy assignment’ instructions, Peer-reviewed panel of the ‘Empathy assignment’ for two groups of students.
  2. [b] Fall 2020: ‘Empathy assignment’ instructions, individual ‘Empathy assignment’ essay from two students, Questionnaire filled out by students after the course ended.
  3. [c] Examples of ‘Knowledge’ and ‘Persuasiveness assignments’.
- **Annex 2**
  1. [1] Personal cases from the co-authors, and a collaborator.
  2. [2] Testimonials and students evaluation
- **Annex 3**
  1. [1] Instructions to build a decision making tool to exercise Persuasiveness (IF Method), to account for people-oriented factors.
  2. [2] IF Method question and Answer
  3. [3] Calculation worksheet provided to students who face difficulties making it themselves.
- **Annex 4**
  1. [1] Fall 2021: example of ‘Final report’ from two groups, including innovation and entrepreneurial elements.
- **Annex 5**

In our experiences teaching about empathy in two quarters (Fall 2020, 9 students and Fall 2021, 26 students), we have observed a wide range of reactions from the students; from very personal and engaged interactions, to more impersonal and critical about the need to discuss it. A similar observation was made by Walther et al. (2020), who executed four modules focusing on Encountering Others, Self and Other Awareness and Affective Sharing, Affective Responding, and Mode Switching, spread over a semester (Fall 2015, 110 students and Spring 2016, 36 students).

The idea of KPE was discussed only with the Fall 2021 group, since it was developed after some of the previous discussions in 2020. Before writing the empathy assignment, we had an open discussion about KPE in the classroom (not included in the grade assessment). This was a very lively experience where almost all students interacted and were triggered about the relevance of the terms Persuasiveness and Empathy. They were not familiar with ‘durable skills’ in the Engineering educational context.

**6.1. Selected testimonials and students evaluation**

For a broader set of testimonials and evaluations from students, please see Annex 2.2. For the experience of 2021, the students gave anonymous responses such as:

- **What was the most valuable aspect of this part of the course?**
  1. [Student 3] I liked how the project was really applicable to a real life problem. And how the techniques in the project were very early stage and not well known yet. This gives a different dynamic compared to the usual projects with set outcomes.
  2. [Student 4] It pushed us in the direction of believing that things can always be improved.

- **What did you find less important?**
  1. [Student 1] I don’t really see the connection between the empathy assignment and the rest of the course. Maybe there is an obvious one, but it was not really clear to me personally.
  2. [Student 5] The empathy assignment. I actually enjoyed doing the assignment. The problem I had with it was that it was not clear to me how it related to the rest of the course or the main project.

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**Fig. 3.** How KPE ratios change with time as the proposed innovation steps are executed. Arrows pointing up indicate that an increase in each ingredient is desirable. Arrows at the top pointing at the thicker black line means that topped up ingredients are ideal, whereas those pointing down indicate less relevance. The entangled symbol in Step 5 indicates mixed and maxed up ingredients during a creative process. The arrow pointing to step one implies the cyclic or iterative nature of innovating processes.
would like it to maybe be changed in a way that it would also be useful for the project.

In 2022, the system to get feedback changed and not all the questions were the same, but here is a set of anonymous reactions:

- Were the learning objectives of this course clear to you?
  1. [Student 1] Not really. The first assignment on empathy was okay and I understood that we had a certain number of assignments to do, however the things we had to do and the deadlines were confusing.
  2. [Student 2] The assessment was well explained.
- Which online teaching activities helped you best?
  1. [Student 2] Empathy
  2. [Student 2] The assessment was well explained.
- Did you use Empathy before in your work? (specify if knowingly or not). Do you think of using empathy in your engineering design process?
  1. [Student 3] Yes, when trying to design solutions to increase the life quality of patients.
  2. [Student 4] Yes, to engage with my co-workers. Empathy could indeed be useful for the design and implementation of ideas.
  3. [Student 5] I think I have used it knowingly but without specifically naming it. I plan to continue using it as this is what allows me to find problems to solve and to design a proper solution.
- What you think is the best aspect of combining KPE? Can you please provide some weak aspect(s) you may have identified in this combination of ingredients?
  1. [Student 3] It’s a nice schematic to describe the broad process of designing and implementing a new product/idea. Weak aspect: might be to general to be applied in detail to real life problems.
  2. [Student 4] The best aspect is that the framework includes the nature of human beings, i.e., ideas and applications are done for and by humans. Something that is normally overlooked when teaching engineering/science.
  3. [Student 5] I think the strongest aspect of combining KPE is that it is oriented at effective provision of solutions to real-life problems. This is what I consider to be the core interest of any engineer. In terms of weak aspects: I think that sometimes people may not understand the importance or a genius of a solution before they see it. In such cases the best option is to replace ‘persuasiveness’ with ‘perseverance’ and convince the stakeholders at a later stage with a ready solution. I think this is what the KPE framework does not consider.
- Do you think that empathy is important for science education?
  1. [Student 3] Yes, for everything.
  2. [Student 4] Yes, otherwise we might not be able to solve the important problems of society or even convince the public that science is a key tool to solve them.
  3. [Student 5] Yes. If our goal is not only to understand the world around us but also to improve it, then we should teach empathy - not necessarily directly but it should be introduced in one way or another.
- Are you more aware of people-oriented solutions, even when faced with a technical problem?
  1. [Student 3] I think I was always subconsciously aware, maybe now a bit more consciously
  2. [Student 4] Not sure what is being asked.
  3. [Student 5] In general - yes. That being said, I think it really depends on a particular problem and on for whom I provide the solution.

For us it was interesting to see how the expectations of the students varied, and sometimes contradicted each other. We noted that in 2022, one group included spontaneously in their final report a section on ‘Empathy’ (see Annex 4 Group 3). This indicates that they had incorporated the learning experiences from the previous activities (writing the empathy assignment and in-class discussion).

Based on the richness of the responses given by the students, and the complexity of the topic, we are now preparing a more structured set of activities to better connect all the elements discussed around KPE and innovating actions. We are aware that the feeling and opinion of the students that did not answer are important, and we will design new ways to get their input instead of volunteering to fill the questionnaires. What we consider a success is that we have made all students aware of the existence of a human-related component to the role of engineers in society.

We also consulted a Social Sciences MSc student to evaluate the feedback from the students and their project reports (see the expanded answer in Annex 2.2): “(…) the course looks interesting and that I find it very cool to see empathy also find its place in engineering as an important value. (...) The creative applications of engineering in conjunction with empathy showed a lot of promise in the students’ thinking. In my view it is great to see and I looked for ways to enhance the channel that creativity and innovative thinking around the problems and solutions the students found.” The input from this student was used to improve the activities in 2022.

The reflections from a PhD student about KPE also gave us more insight (see the expanded answer in Annex 2.2):

“Humans are egocentric by design and we tend to prioritize our immediate needs over that of many nobler causes. The effect of this egocentric (or unempathetic) approach is far-reaching. (...) Problem solving today must invariably take into account socio-economic impact. Not only do the most pressing problems we currently face have enormous social effects (such as climate change disproportionately affecting the poor), but markets are also beginning to adapt to an increased appetite for socially-conscious initiatives. This is where empathy plays a crucial role. A conscious attempt at empathy (which surely most of us are capable of) can help sway the entrepreneurial process toward some of the most pressing challenges of our time without overtly stymying general capitalist innovation. As a PhD candidate (at the time of writing), the role of knowledge is clear and quite frankly, fundamental to my line of work. I must however, admit that I’ve overemphasized the K aspect thus far. I haven’t fully appreciated the impact that the other two components have had on my career. Empathy, in particular, has played a pivotal role in bringing me this far. (...) Most people I compete with for academic positions have good, if not better, academic credentials - the K factor doesn’t play a determining role. It helps if you can demonstrate P and E. This goes to show that the KPE framework is extensible beyond entrepreneurship - it can provide tangible benefits to one’s career while still making meaningful contributions to society.”

A colleague from the Centre for Educational Support from our university summarised the KPE framework as follows:

“In my opinion you came with a teaching method to train engineers of the future who are human and technical THE combination in the ‘google- generation’ to make a real difference. We need smart engineers how can listen to the client, translate wishes in ‘normal language’ to extraordinary ideas/products etc.” She also reminded us that the philosophy of our University of Twente is: “High-tech, human touch”, UTwente (2022).

7. Conclusions

We have argued that the KPE framework enables gaining higher order abilities e.g., relationship building and adaptability, thus giving us a starting point to educate more innovative and entrepreneurial engineers. To enable effective and sustainable innovation, we have proposed a more explicit inclusion of persuasiveness and empathy education in technical fields, in particular for Chemical Engineering.

The KPE framework we have introduced may help define common ground that facilitates the exchange of best practices and results between professions which do not generally emphasize empathy, e.g., engineering, and others which do to some degree, e.g., many medical
We provide six steps which embody the principles of the KPE framework. These steps are not a checklist of processes which students must rigidly follow, but instead one demonstration of the links between knowledge, persuasiveness, empathy, and the actions undertaken in the pursuit of innovation. We hope that these steps can be applicable in courses, no matter the complexity or dependence on equipment or in long-distance learning settings.

We have introduced a ‘persuasive’ tool, the IF method, that helps to arrive at a numerical approximation when deciding whether to continue expending resources during a project, or can be used to persuade different stakeholders. Moreover, it is a pedagogical tool that provides students with a simple numerical argument used in their educational projects.

Gauging the actual number of study programs that address elements of durable skills, in part or totally, will help identifying the magnitude of the current gap and monitor the progress as more teachers and universities incorporate the link between the KPE ingredients. Instead of advocating for making separate courses where durable skills are taught, it would be more effective to be explicit in our teaching within existing courses or programs. Engineers need to be reminded ‘why do we do this type of work’, without reducing the focus on the other ‘technical’ courses.

To make a gradual shift towards teaching durable skills along the curricula, we propose using existing courses or specific moments where it will be easier to test some of the activities we have proposed based on KPE, such as capstone programs/projects. These projects can be executed over a semester or over an academic year, which allows for a true training in professional aspects and maturing ideas and internalising what an ‘engineer can do’. This maturing process may be accompanied by reassessments and alterations to the initial project ideas, where the IF method can assist in persuading stakeholders or the students being persuaded themselves.

To prepare the students for these programs (typically in senior years in the curriculum), the curricula could include simple elements of durable skills, such as small role-play experiences. We are reaching out to different faculties in our own University and other experts worldwide to exchange ideas and identity the best practices.

What is more, the KPE framework raises awareness and training on attaining durable skills. When combined with real-life examples with strong academy-industry linkage, it increases awareness about the importance of entrepreneurial skills and sustainability approaches. All of the above can certainly increase the employability of the future engineers, and sharpen the focus of professionals in the workforce. In sum, we see Knowledge, Persuasiveness and Empathy as fundamental ingredients for life-long learning in Chemical Engineering.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Conflict of interests

DFR is co-founder of the company BuBclean, located in The Netherlands, and has financial interest in it.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ece.2022.05.002.

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