Decision Making Skills in Engineering Education

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ABSTRACT

Professional and personal life environments are more than ever Volatile, Uncertain, Complex, and Ambiguous (VUCA). Therefore, there is a growing concern about responsibility of decision makers. This system paper focuses on decision making (DM) skills in engineering education along three complementary dimensions: Maths-based, Social-based, and Career-based. The review of existing learning activities prepares a transversal decision skills learning outcomes framework for the iterative development of engineering students, in line with the evolution of graduate engineering profiles and their proficiency levels in VUCA contexts.

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INTRODUCTION

Nowadays, reliability depends on the ability of the actors to organize and reorganize in order to anticipate and cope with unexpected situations, which requires skills of improvisation, creative bricolage, and attitude of wisdom [1]. The context of this system paper is the growing concern about responsibility of decision makers. The world is complex, with multiplex of forces and no cause-and-effect chain. Whether they are to act in STEM or other fields, future engineers should be specifically prepared to making decisions in VUCA environments, i.e. Volatile, Uncertain, Complex, and Ambiguous situations. But what skills should future engineers possess in their curricula to prepare them to reliable DM in VUCA environments?

1 PROGRAMME OUTCOMES AND TRANSVERSAL SKILLS

1.1 Accreditation requirements

The European Qualification Framework, recalls at level 5 “competence to exercise management and supervision in contexts of work or study activities where there is unpredictable change”; and at level 6 “to manage complex technical or professional activities or projects, taking responsibility for DM in unpredictable work or study contexts”. Decision is not only about knowledge, it is also about skills. Skills relate to the “ability to apply *knowledge* to complete tasks and solve problems. Skills can be described as cognitive (use of logical, intuitive and creative thinking) and practical (involving manual dexterity and the use of methods, materials, tools and instruments)” [2]. The ENAEE, which sets Programme Outcomes for Engineering Education accreditation in EU [3], introduced in 2015 priority in Decision Making and Judgment abilities. From now on, in Europe, the learning process should enable Master Degree graduates to demonstrate:

- ability to manage complex technical or professional activities or projects that can require *new strategic approaches*, taking responsibility for DM;
- ability to *integrate* knowledge and handle complexity, to *formulate* judgements with incomplete or limited information, that include reflecting on social and ethical responsibilities *linked* to the application of their knowledge and judgement.

More internationally, in the CDIO Syllabus [4], decision analysis with uncertainty (ref. 2.1.4) and initiative and willingness to make decisions in the face of uncertainty (ref. 2.4.1) are requirements for personal and professional skills. Making complex technical decisions with uncertain and incomplete information is also a requirement for exercising judgment and critical reasoning (ref. 4.7.7).

1.2 Multidimensional and transversal decision making skills

The concept of decision has multiple dimensions. For engineers, DM echoes in scientific methods (e.g. Math-based), human environment (e.g. Social-based), or even in professional pathways (e.g. Career-based). DM skills are also transversal (i.e. “skills acquired in one context that, with adaptation, may be applied in another context” [2]). Students must thus capture the multiplicity of contextual factors influencing individual and / or collective DM processes.

As an example, complexity can lead to information overload with effects on the DM process. Most people, and especially engineers, use mental strategies called heuristics to cope with the complexities of making estimates. But these heuristics can lead to systemically biased judgments (e.g. over-optimism). Heuristics could thus lead to erroneous decisions. Moreover, a new heuristic requires a learning time. But in VUCA contexts under a too volatile environment, actors will not have resources to mobilize adequate heuristics, leading possibly to dramatic consequences. Uncertainty and ambiguity have also consequences on the level of performance. VUCA conditions strongly affect the decision capacity. One has to understand VUCA characteristics and sources, and their effects on DM processes.

2 MATHS AND SOCIAL BASED DECISION MAKING SKILLS

2.1 Rationality and uncertainty

The giant leap in mathematical approach to DM arguably goes back to 1202 with the publication of *Liber Abaci* by Fibonacci [5]. From a mathematical viewpoint, DM skills emerged in gambling with players constantly estimating their odds. However, the rational view of decision making involves not just an evaluation process. The agenda followed nowadays by normative DM consists in providing modelling tools to help the decision maker / student to learn about the situation at hand. As such contingency between strategies, uncertain events and main objectives of the decision process must be elicited. Finally, decision is also about decision making and finding adequate rules for deciding. Multicriteria analysis and expected utility provide methods dealing resp. with multiple objectives and risky (known probabilities) DM. One limitation of the frequentist approach to probability estimation under risk is the handling of uncertain situations (i.e. not experienced before) and subjective expected utility was proposed. Procedures have been proposed to cope with human subjective probability elicitation and bias. Taleb [6] claims that the fundamentals of using probability distributions for estimating the impact of events on outcomes are idiosyncratic. This leads to what Taleb calls ludic fallacy for explaining the drawbacks of using the basic axioms of probability to estimate future uncertainty. Students have to understand the scope and limitations of mathematical decision-making methods and of computing tools. The field of decision analysis, originally mostly a mathematical discipline, has evolved into a useful method for industry and government, to help decision makers gain a greater understanding of the problems they face. In this perspective, decision aid is not a method for discovering the truth but rather methods aimed for helping students/decision makers to think and gain knowledge about the situation at hand, enabling thus a better decision process than just intuitive decision making.

2.2 Complexity and VUCA contexts

The most fundamental capability of human beings is arguably conscious DM. Generally, decisions are made in non-emergency situations but often under a high degree of uncertainty. Even in these regular situations, DM suffers from cognitive bias under human limited cognitive and information-processing capacities such as inaccuracy in terms of project uncertainty, unreliable or out-dated data and the use of inappropriate forecasting models [7]. In addition, sociological forces interact with these psychological limitations and affect individual behaviour if groups act without a clear coordinating mechanism. In a social learning context, group forces and motives are important, reflecting not only conformism, social imitation or conscious identification with group but also group-centred goals and behaviour. The complexity created when individuals interact under potentially conflicting objectives removes the objective of rational DM even further away. With game theory, Von Neumann's proposal was to set up for the social sciences the same rigorous scientific methodology as in physics. The game theoretical approach can be criticized notably by reducing the modelling of the real situation too drastically. Agent based modelling and participatory simulation have been one response to deal with this problem. Stakeholders and modellers built up a serious game of the situation they are confronted to. Once a game has been designed and agreed upon, learning by playing the game is one way to design “efficient” solutions for the participants.

In VUCA contexts are characterized by dynamicity and emergency. Mechanisms to detect early signs of crisis and react at time are required. This point is a key element of High Reliable Organizations (HRO) [8] which seeks to understand the normal functioning of human-based decision systems by identifying the characteristics of HRO and explaining their exceptional performance. To reach a higher level of reliability, Roberts recommends flexibility in the decision-making process. Weick [1] identifies three characteristics of HRO in contexts where the error is unforgivable: information overload, constant turbulence, and increasing complexity. Unlike other theoretical frameworks on reliability (e.g. Theory of Normal Accidents), the HRO and Actionnist currents have even the specificity to consider human behaviours as a source of reliability rather than of failure. These organizations are able to create and maintain a state of collective watchfulness thanks to the quality of the interactions between their members [9]. Weick mentioned that respectful interactions, a system of roles, improvisation, and watchfulness are the four sources of reliability. A work on VUCA conditions from this theoretical works is supposed to answer the limits faced by maths-based decision making methods. The authors suggest to use this approaches which take into account VUCA parameters, as active learning courses.

3 LEARNING ACTIVITIES

3.1 Active learning activities

As online course examples, ESSEC Business School created the MOOC “*L'avenir de la decision: connaître et agir en complexité*” (Edgar Morin chair, fr.coursera.org/learn/lavenir-de-la-decision), composed of videos and lectures, including knowledge oriented courses. Aside, students may learn from real experiences, to develop and reinforce their decision competencies. There are other on-line university courses in decision engineering such as that given by the Rey Juan Carlos University of Madrid [10], designed for students to learn to make the best decisions in less time and to analyse them in a globalized world. With these courses, students are expected to improve their DM process and quality of decision taking.

Various pedagogical models exist to reinforce collaborative dimensions and practical skills in STEM curricula (e.g. Problem-based learning, project-based learning). In formal curriculum, the Disaster Week, initiated at Reykjavik University [11], exposes students to real-life engineering, as a multidisciplinary introductory course. With one week of team work, students are to develop an action plan for dealing with an unforeseen event of some complexity, demanding DM, fast based on incomplete information. Topic includes a natural disaster, e.g. a potentially devastating epidemic in Iceland or a volcanic eruption with the lava flow towards the city. This style of learning enforces the importance of teamwork, the need to gather information quickly, and one has to make decisions fast based on incomplete information. It permits to meet intended learning outcomes for freshmen around Maths-based DM.

At IMT Atlantique, graduate engineering school, the Springfield serious game exposes students to real cases in order to show the complexity of actions and decisions in risky situation. The context is an accident which occurred in a nuclear plant. Each player has a specific role, with specific objectives and information (a plant manager, a safety engineer, and operators). Players have to work together in order to save the plants. In debriefings, students explain their behaviour and decisions.

3.2 Towards experiential learning activities

Future graduates are to be able to turn knowledge into skills. The complete development of a competence is better covered by various integrated learning activities, including real experiences or work-based learning models. For DM skills, in all its dimensions, experiential and cooperative learning is the key for Teaching & Learning innovation. Some courses permit to show by experience that DM is a complex process, particularly when the decision leads to irreversible consequences.

At IMT Atlantique, an inter-semester course (2 ECTS) trains students to take decisions and react in unexpected and unpredictable situations [12]. Using an experiential learning model as proposed in the French Naval Academy, the one week course has some outdoor elements in the sea environment for novices. The real experiential situations so selected reflect nautical risk scenarios with levels of complexity and time pressure (including Man Over Board exercises, cf. Figure 1), where specific decision skills are to be acquired or reinforced, such as risk and priority management, watchfulness, team management with respectful interactions, judgement and responsibility, etc. Participants also have to prepare a navigation (weather, equipment, refuelling, practical information), plan the stages, estimate the navigation times, the possible risks and dangers, prepare the most delicate passages, prepare fall-back solutions and identify success factors. Just like a project, the success of a sailing cruise requires a certain number of technical and human skills. In these real situations, flexibility constitutes the sources of reliability and performance. These in-context experiences are to be useful in an engineer career where responsibilities increase (e.g. decision-makers to face complexity, uncertainty and urgency). A first experience, as a non-expert from the environment, may create a learning-loop for future work-based situations including improvisation [1].

In [12], empirical evidence on motivational factors have been first analysed qualitatively. Based on direct observations and experiences, quantitative analysis is now under investigation to determine how to better prepare future engineers to make more reliable decisions in VUCA environments. One and team DM skills are thus formalized in program components, as transversal, with aforementioned learning outcomes and VUCA-based progressive proficiency levels. In the context of an ongoing Erasmus project, design-based research methodology is also under consideration in order to conceptualize experiential learning activities and iteratively analyse learner achievement, program coherency and framing.

The experiential scenarios proposed in [12] rely on theoretical frameworks dealing with reliability. They use the four sources of reliability as assessment criteria and include situations with a high level of complexity, uncertainty, and time pressure that future decision makers are supposed to face in their future professional activities. As learning outcomes, the learning process should enable graduates:

- to tackle moral, ethical, and social issues of a situation;
- to identify sources of uncertainty, face complexity and continuously recognize and qualify the criticality of a situation, including its events and factors;
- to accept uncertainty, fix priorities and formulate judgment on situational events individually and collectively;
- to react flexibly to events and regularly assess the weight of an error in the DM process;
- to take initiative and responsibility on choices and actions during the situation, and reflect from experiences in order to increase resilience.

Fig. 1. Collective urgent rescue.

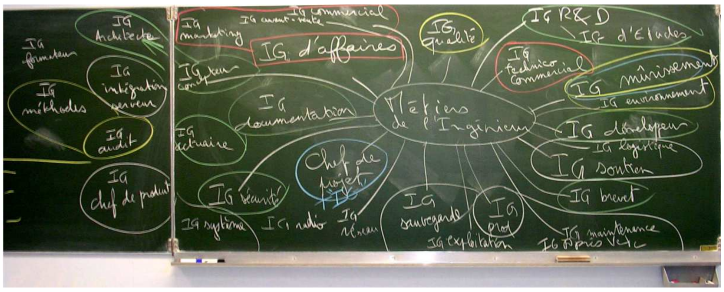

Fig. 2. Job map, from [14].

4 CAREER BASED DECISION MAKING SKILLS

Investigations on courses including progressive VUCA circumstances should also facilitate the integration and career paths of young engineers in their professional life and workplace. Engineer diplomas greatly facilitate first job offers and open up on broad career possibilities in many economic fields where engineers may often exercise their potential as leaders and future decision makers. However, uncertainty and indecision often result from student appraisal of the career kaleidoscope. Some struggle to identify career directions and therefore need some time before feeling committed and being operational within their curriculum and first jobs. The European Lifelong Guidance Policy Network (www.elgpn.eu/) regards career management skills as competencies which help individuals to identify their existing skills, develop career learning goals and take action to enhance their careers.

It is thus critical to reinforce students' self-confidence, especially when considering that the recruitment market is becoming more and more demanding and competitive for newly graduated engineers. Students' perception of a profession can strongly influence their career choices. In addition, yet many students who have had only limited exposure to a profession may base their decisions on limited or distorted perspectives, for example a single internship or co-op experience, both positive and negative [13].

It is essential to provide students with means which will enable them to participate actively in their own learning and develop a long-term aspiration for future career paths. As learning outcomes, the learning process should enable graduates:

- to know oneself and analyse his/her set of skills;
- to gather information, identify options, and explore career options;
- to recognize and define one's choices;
- to define career paths, to plan and evaluate them, to select options;
- to gain flexibility and propose a coherent professional project including career orientation, and to combine personal development therewith.

Traditionally, educational institutions design career preparation programs which focus on making their students more attractive to potential employers. As example, in a University context, the Department of Guidance and Professional Insertion of the Foundation University-Enterprise of the Balearic Islands has realized the Occupational Guidance and Occupational Assistance Program. This non-compulsory program aims to guide and improve the possibilities of self-employment of the university graduates and students who are seeking employment. Concretely, it permits to improve employment opportunities by designing a personalized itinerary for job placement. This personalized itinerary consists in the realization of individualized sessions of professional orientation: how to properly take decisions to get a job, how to apply for a job interview to get an employment. Students learn the ability to make the right decisions from the individualized orientation sessions. At IMT Atlantique, a compulsory 63h career preparation course is in place since 2007, to disclose to students, via active workshops over three years, their career perspectives (cf. Figure 2), enable them to participate actively in their own learning path, to build their future professional identity, and to plan proactively their future career [14], in VUCA workplace contexts.

5 SUMMARY AND ACKNOWLEDGMENTS

In a rapidly changing world, the VUCA context requires now to rethink the vision for engineering education [15]. As seen today in the European society, the nature and dynamics of change creates unpredictability and future engineers are to manage complex situations with critical reasoning. Professional life environments are more than ever VUCA. This context makes decisions even more strategically critical. But as Le Boterf defends it [16], a skill is only effective once it has been tested and validated thanks to its confrontation to reality. To prepare future engineers to make more reliable decisions in VUCA environments, experiential learning models are a key, all along a curricula with a transversal skills approach. This system paper thus supports the coherent inclusion of active and engaging pedagogical models, with DM as a transversal skill, in association with three complementary and unified dimensions including learning outcomes:

- Maths-based DM, with rationality;
- Social-based DM, including people’s interdependencies and social identities;
- Career-based DM, according to own career path.

Decisions rely on many factors, context-dependant. A dedicated decision framework is to provide support for faculty staff to improve student competence in decision skills, interwoven with the learning of disciplinary knowledge and its application in professional environments. Mastering of these skills is to be assessed by various stages of complexity, e.g. from partial application, realisation, adaptation, to anticipation in various VUCA situations. Societal responsibilities are elements of DM and included in the three aforementioned dimensions. The DM learning outcomes are to be indicated to provide a pragmatic guide to deal with the pressing ethical and social considerations. The aim is to ensure that students are educated, trained, and empowered to include ethical and social considerations in their decisions, diminishing negative consequences in their future work, professional itinerary, and personal life.

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