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A Plan for a 21st Century-oriented Transformative Educational Change for Anti-fragilizing Future (Safety) Engineers

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***Abstract*—Liquefaction and digitalization are important socio-technical changes that call for actions in education. As stated by Bauman, as a consequence of liquification (and digitalization), uncertainty is increasing. Within this socio-technical context, in this paper, we focus on the necessity of reframing the role of the safety engineer and on the transformative educational change necessary to enable the re-framed safety engineers to cope with uncertainty. We posit that the 21st Century safety engineer is expected to develop antifragility. To contribute to that development and thus educate/ex- dūcĕre antifragility from future (safety) engineers, we focus on one course (code DVA437, aimed at teaching safety-critical systems engineering) and we plan its 21st Century-oriented transformative educational change. We also report about the first iteration of the design of the personal opinion survey that we intend to use for validating our plan, before proceeding with its implementation.**

Keywords: Liquefaction, Digitalization, Safety-critical Systems Engineering, Antifragility.

***Index Terms*—About four key words or phrases in alphabetical order, separated by commas.**

I. Introduction

Liquefaction and digitalization are important socio-technical changes that are shaping our everyday life and call for actions in education. Liquefaction is urgently calling for empowering individuals with a mindset ready for flexibility, change, learning/unlearning/re-learning, critical thinking, while digitalization, meant as the adoption of digital technologies across all possible societal and human activities, is calling for the reframing of the existing roles and the introduction of new ones. As stated by Bauman [1], as a consequence of liquefaction (and digitalization), uncertainty is increasing. Within this socio-technical context, in this paper, we focus on the necessity of reframing the role of the safety engineer and on the transformative educational change necessary to enable the re-framed safety engineers to cope with uncertainty. We posit that the 21st Century safety engineer is expected to develop antifragility [2], i.e., the ability to gain from disorder. By developing antifragility, the engineer will also develop and even go beyond the key competence for life learning identified as *Personal, social and learning to learn competence* by the European Commission [3]. To contribute to that development and thus educate/ex- dūcĕre antifragility from future (safety) engineers, in this paper, we focus on one course (code DVA437, aimed at teaching safety-critical systems engineering) and propose our plan for its 21st Century-oriented transformative educational change. Specifically, we propose to incorporate, into the re-designed teaching and learning actions, educational strategies, inspired by the liquid modernity's metaphor and the antifragility-related concepts, such as asymmetric optionality, the barbell strategy, and hormesis. In compliance with best practices in safety-critical systems engineering, we follow a certification-liaison process-like [4], we first plan and then, to validate our plan, before proceeding with its implementation, we partly design a questionnaire expected to be completed and used to conduct a personal opinion survey [5] among safety experts (safety engineers, safety managers, teachers active in safety-focused education as well as former students holding safety-related positions) in industrial and higher education settings.

The rest of the paper is organised as follows. In Section II, we recall essential background information. In Section III, we present our plan for the 21st century-oriented transformative educational change for antifragilizing future (safety) engineers. In Section IV, we report about the first iteration of the design of the personal opinion survey intended to be used for validating the plan. In Section V, we discuss related work. Finally, in Section VI, we summarize our paper and present the intended future work.

II. Background

In this section, we provide the theoretical underpinnings for the development of the plan. Specifically, we recall essential information about: a) Bateson's model of the logical types of learning; b) liquid modernity and unlearning strategies; c) antifragility and its related concept as well as phenotype and its plasticity; d) key competence for life-learning, e) the DVA437 course on safety critical systems engineering, and f) the DO-178C-compliant Certification Liaison Process.

A. *Logical types of Learning*

Gregory Bateson introduced a model of logical types of learning [8]. In this paper, we recall the first 4 types.

- **Specificity of response**, alias **Learning 0**, captures the ability to respond to a stimulus/sensing without introducing changes based on experience or information;
- **Proto-learning**, alias **Learning I**, captures the ability to learn, i.e., moving by realizing cognitive, conative and affective changes in knowledge, skills and attitude-change of Learning 0;
- **Deutero-learning**, alias **Learning II**, captures the ability to learn to learn, i.e., change Learning I;
- **Learning III** captures the ability to change the rules, to free oneself from habits, to modify the set of alternatives he/she learnt during the deutero-learning process.

B. *Liquid Modernity and Unlearning Strategies*

Zygmunt Bauman coined the concept of **liquid modernity** [1] to describe the condition of constant change in all aspects of human life (e.g., identities, relationships, education, and global economics) within contemporary society. He visualized liquid modernity as a condition, opposite to solid modernity, resulting from as well as emergent as a consequence of the destructuring and deregulation processes that are taking place in all aspects of human life. Regarding education, in [9], Zygmunt Bauman revisits Gregory Bateson's work on types of learning and highlights that the tertiary learning (Learning III) is fundamental to survive in liquid modernity.

We interpret Learning III as the enabler of the transition from solid learning to liquid learning.

Learning III or unlearning has been investigated since its conceptual introduction. Recently, Makoto Matsuo has conducted a series of studies to investigate what enables unlearning [10]. Specifically, he examined the effect of goal orientation[1] and (critical) reflection[2] on individual unlearning using survey data. From his studies it emerges that: learning goal orientation is a main driver of critical reflection, which leads individuals to unlearn. It also emerges that critical reflection has a direct effect on individual unlearning, while reflection has not. However, reflection is always an antecedent of critical reflection. The reader may refer to [10] for more details on unlearning-related findings.

C. *Antifragility, Phenotype and its Plasticity*

In this subsection, we recall the concept of antifragility. In addition, since, in this paper, we target the contribution to the development of antifragility of future safety engineers, who are complex biological systems, we also recall concepts related to biological systems evolution, i.e., phenotype and phenotypic plasticity.

Anti-fragility [2] is defined as the property that characterizes systems able to gain from disorder, including disorder generated by the occurrence of black swans [11], i.e., events that 1) are so rare/isolated that even the possibility that they might occur is unknown, 2) have a enourmous impact when they occur, and 3) are explained in hindsight as if they were actually predictable. Antifragility is not a synonym of resilience. Even if a system that exhibits resilience is capable of coping with uncertainty, it does not gain from disorder. It does not change itself and hence does not improve. Antifragility can be exemplified with weightlifting thanks to which muscles grow under reasonable stress.

To develop antifragility, asymmetric optionality, the barbell strategy, and hormesis represent key instruments. Hence in what follows these concepts are recalled.

Asymmetric optionality [2] indicates the right to do something without the obligation to do it. Taleb's idea is to seek out or create options that have a strong upside, but very low cost or downside (i.e., things, people and habits that make us vulnerable to risk and volatility).

Barbell strategy [2] consists of a bimodal strategy, a combination of two extremes, one safe and one speculative. Such bimodal strategy is deemed more robust than a mono-modal strategy. Taleb exemplies the strategy in the financial domain and then illustrates its application in various domains. In the financial domain, a barbell strategy is characterised by maximal certainty/ low risk in one set of holdings, maximal uncertainty in another. More precisely, it consists of the mixing of two extreme properties in a portfolio such as a linear combination of maximal conservatism for a fraction of the portfolio, on one hand and maximal (or high) risk on the remaining fraction.

Hormesis [12] refers to the evolutionary conserved adaptive responses of all living organisms to mild environmental, nutritional or even voluntary challenges through which the system amends its tolerance to more dangerous stress factors. According to Taleb, hormesis is a form of proto-antifragility. Its contribution to antifragility is temporary.

In biological terms, being able to gain from disorder and becoming stronger is translated into a reconfiguration that manifests itself via a different phenotype.

As pointed out it [13], the predominant current-day meaning of genotype is some relevant part of the DNA passed to the organism by its parents. The **phenotype** is the physical and behavioral traits of the organism. An organism's phenotype results from two basic factors: the expression of an organism's genetic code, or its genotype, and the influence of environmental factors.

As recalled in [14], **Phenotypic plasticity** is the ability of an organism to express different phenotypes depending on the biotic or abiotic environment. The modern view of plasticity can be generalized to the statement that phenotypic plasticity

[1] *Goal orientation* refers to one's dispositional or situational goal preferences in achievement situations. Goals are classified into performance goals and learning goals. Specifically, individuals who have performance goals are concerned about gaining favorable judgments of their competence, while individuals who have learning goals are concerned about increasing their competence [10].

[2] *Reflection* consists in periodically stepping back to ponder the meaning of what has recently transpired to us and to others in our immediate environment. Reflection focuses on the immediate, presented details of a task or problem; *critical reflection*, instead, involves the critique of presuppositions concerning "problem posing" that can make a situation that is taken for granted problematic, thereby raising questions regarding their validity. Critical reflection concentrates on an examination of the assumptions being taken for granted within which the task or problem is situated [10].

evolves to maximize fitness in variable environments (the adaptive plasticity hypothesis).

D. Key Competences for Life Learning

A competence is defined as the capacity to deal successfully with certain situations or tasks. The Council of the European Union adopted a Recommendation on key competences for lifelong learning in May 2018. The Recommendation [3] identifies eight key competences essential to citizens for personal fulfilment, a healthy and sustainable lifestyle, employability, active citizenship and social inclusion. In this paper, we focus on one: *Personal, social and learning to learn competence*, which is briefly described as ability to reflect upon oneself, effectively manage time and information, work with others in a constructive way, remain resilient and manage one's own learning and career. It includes the *ability to cope with uncertainty and complexity*, *learn to learn*, support one's physical and emotional well-being, to maintain physical and mental health, and to be able to lead a health-conscious, future-oriented life, empathize and manage conflict in an inclusive and supportive context.

E. DVA437

DVA437-*Safety critical systems engineering* is a 7.5 ECTS advanced course. DVA437 is part of various Master's programmes at Mälardalen University and contributes to shaping (safety) engineers. DVA437 was introduced for the first time in the fall semester of 2011 as 10-week course at a pace of 50%, i.e., a total student effort of around 20 hours per week. The Intended Learning Outcomes of the course are:

1. Apply fundamental methods for hazard analysis. From a knowledge perspective, this ILO requires that students reach a mastery in dependability terms and concepts.
2. Apply safety standards for development of safety-critical systems. From a knowledge perspective, this ILO requires that students reach sufficient knowledge about safety life-cycles used in specific domains.
3. Create a safety case. From a knowledge perspective, this ILO requires that students reach a mastery in argumentation-related terms, concepts, and practices.
4. Compare and contrast his/her work with respect to state of the art concerning safety case structuring.

These ILOs capture essential skills, typically required by companies when advertising job offers related to safety engineer-positions. These ILOs were formulated according to the SOLO (Structure of the Observed Learning Outcome) taxonomy and the course has been designed according to constructive alignment principles combined with the education-oriented ISO 26262 interpretation [6], where ISO 26262 is a standard for functional safety in the automotive domain. DVA437 is an advanced course. Hence, it expects students to reach in-depth knowledge and skills. The third ILO "create a safety case", for instance, explicitly states the expectation for the so called "extended abstract" level of understanding. Students are examined via a written exam as well as project work, which includes an oral presentation, during which students are not only expected to present orally their work but also act as opponents/discussants while class-mates present. The project work always proposes real life challenges provided in cooperation with industrial partners.

Before the spreading of the corona virus, DVA437 was delivered on campus via regular interactive theoretical lectures and guest lectures, typically given by industrial partners. During the pandemic, as reported in [7], DVA437 was re-designed and delivered as a series of on-line meetings in compliance with the Community of Inquiry (COI) Model.

F. DO-178C-Certification Liaison Process

The purpose of DO-178C [4] is to provide guidance for the production of software for airborne systems and equipment that performs its intended function with a level of confidence in safety that complies with airworthiness requirements. The guidance includes the objectives, activitities, and evidence related to a series of life-cycle processes, i.e., planning process, development process, and integral processes. The certification liaison process is an integral process which focuses on the communication between the applicant and the certification authority. The applicant is expected to gain agreement on the means of compliance through approval of the Plan for Software Aspects of Certification.

III. A Plan for Anti-fragilizing Future Engineers

In this section, based on the theoretical underpinnings recalled in Section II, we propose our plan for a 21st century-oriented transformative educational change for anti-fragilizing future (safety) engineers. Our plan aims at introducing a transformative educational change that in turns has the potential to trigger the student's transformative change, i.e., making him/her antifragile and ready to cope with uncertainty. To do that our plan incorporates the tertiary learning (recalled in Section II.A-B) and the antifragility-related concepts, which were recalled in Section II.C, i.e., the asymmetric optionality, the barbell strategy, and hormesis.

A. DVA437-ILOs Revision

The current DVA437-ILOs are well conceived to develop skills needed in safety engineering. We believe that these skills will be required also in the coming decades. Our belief is supported by the engineering practices, which include the development and application of standards, which in turn provide recommendations about objectives, activities, and methods regarding hazard analysis as well as safety case development. We postulate that future (safety) engineers will still have to deal with standards (ILO-2), hazard analysis (ILO-1), justification engineering via argumentation (ILO-3). The ability of comparing and contrasting their work with respect to state of the art concerning safety case/justification structuring will also remain a key skill (ILO-4).

However, given liquefaction and digitalization, the future (safety) engineers will have to cope with increased uncertainty and their role might require to become liquid as well with a set of expanding/shrinking responsibilities in relation to the dynamic working context which in addition to the typical dynamicity (relocation, change of hierarchical position, etc.)

may change also as a consequence of the technological disruptions (e.g., increased automation) which entail disruptions in terms of business models.

Within the current ILOs, no explicit learning outomes is present to require the development of skills necessary to cope with uncertainty. Hence, we propose to revise the ILOs-related section of the syllabus and include a meta-ILO: critically reflect upon your learning/unlearning and antifragility strategies.

B. DVA437-Teaching Activities Revision

As recalled in Section II.E, DVA437 was recently re-designed in compliance with the Community of Inquiry (COI) Model. As it emerged from the COI-specific questionnaire (cognitive perspective), this redesign contributed to the learning goal orientation. The majority of the students, who participated to the questionnaire, strongly agreed to "I felt motivated to explore content related questions" and "course activities piqued my curiosity". As seen in Section II.B, learning goal orientation is a main driver of critical reflection, which leads individuals to unlearn. The redesign of DVA437 also included explicit (critical) reflection-oriented momenta. As seen in Section II.B, critical reflection has a direct effect on individual unlearning.

It is also worth to point out that dependability concepts as well as argumentation means are introduced by considering their historical evolution. This historical perspective naturally creates room for discussion/critical reflection on the need of learning/unlearning. Thus, (critical) reflection-oriented momenta do not need to be revised.

Regarding antifragility, the current set of lectures on dependability and its evolution covers the concept of antifragility. Antifragility, however, as being a novel concept, is mainly introduced to students to inform them about its existence and trigger their curiosity about it. Hence, the revision plan consists in extending this set of lectures to include additional material on antifragility to be able to reach an operational uncerstanding of the antifragility concept and its related concepts and strategies. This extension would enable students to perform a crititical reflection as expected by the proposed ILO-5.

C. DVA437-Learning Activities Revision

In addition to the learning activities currently proposed within DVA437, students would have to: 1) deepen their learning regarding the concept of antifragility, and 2) (critical) reflect upon their learning/unlearning and antifragility strategies via active participation in questionnaires, Canvas-discussion threads, (critical) reflection-oriented momenta embedded within the lectures.

D. DVA437- Examination Activities Revision

Currently, ILOs are examined via a written examination and project work, both examination types challenge the students in various ways. In addition, the project work includes hormetic stressors since it requires students to manage their time and meet the deadlines. These stressors however do not take into consideration of the individual characteristics and thus may act as eustress (enabling the development of antifragility) as well as distress (decrease of performance).

As seen in the background section, the hormetic stressors have the potential to trigger a reconfiguration and a different manifestation of the phenotype. Theoretically, their usage is appealing. However, since the identification of the right dose of the hormetic stressors would require individual-measurement to ensure "eustress" instead of "distress", the plan is to revise the examination activities by focusing on the incorporation of elements related to: asymmetric optionality, the barbell strategy, and unlearning. Specifically, *regarding the asymmetric optionality*, students would have the option (but not the obligation) to extend their 4th project assignment on the state of the art aiming for a scientific paper. *Regarding the barbell strategy*, once the concept is understood, they would have the opportunity to apply it on the examination itself by devoting time to securing points in order to pass (minimum threshold) the exam/project parts that are of less interest for them and devote the remaining time to engage in the exam/project or other activities that may contribute to nourish their passions. Finally, *regarding the unlearning*, the plan is to borrow from the findings reported in [10]. Specifically, the plan is to include critical reflection-oriented assignments within the project work and written examination. Precisely, a meta project assignment of the type "after-event-review" will be included to enable students to critically reflect upon their learning/unlearning and antifragility strategies regarding the project work. Within the written examination, a question of the type "after-event-review" will be included to enable students to critically reflect upon their learning/unlearning and antifragility strategies regarding the written examination.

IV. Questionnaire-based Opinion Survey Design

A personal opinion survey [12] is a comprehensive research method for collecting information using a questionnaire completed by subjects. This research method consists of six main activities: 1) setting the survey's objectives; 2) selecting the most appropriate survey design, e.g., cross-sectional (participants are asked for information at one fixed point in time). It is also essential to define how the survey is expected to be administered, e.g., self-administered; 3) constructing the survey instrument (concentrating on self-administered questionnaires); 4) assessing the reliability and validity of the survey instrument; 5) administering the instrument; and, finally, 6) analysing the collected data.

In this section, we focus on the first three activities as follows.

A. Survey Objectives

The overall goal of this survey is twofold 1) to collect opinions about the skills that a 21st Century (safety) engineer is expected to have to cope with the globally increasing uncertainty and the challenges posed by highly complex systems developed and deployed within an uncertain environment. 2) collect opinions about the potential contribution of the planned revision of DVA437 to the development of such skills.

Spcifically, we formulate the following research questions:

Which skills a 21st Century safety engineer shall have?

Does the planned revision of DVA437 have the potential to contributure to the development of such skills?

B. Survey Design and Questionnaire Creation

In this section, we document the first iteration of the design of the cross-sectional personal opinion survey, whose goal is to collect data relevant to answer the research questions presented in Section IV.A. The survey is expected to be distributed via e-mail. The target population consists of safety experts (safety engineers, safety managers, teachers active in safety-focused education as well as former students holding safety-related positions) in industrial and higher education settings. The survey is expected to be organized into three parts.

1. Demographics. This part includes a set of questions which aim at gathering the background characteristics of the targeted population.
2. Expected skills. This part includes a set of questions which aim at gathering information about the target population' s opinion regarding expected skills that the 21st Century (safety) engineer is expected to exhibit/develop.
3. Plan for DVA437. This part includes a set of questions which aim at gathering information about the target population' s opinion regarding the contribution of the plan for DVA437 to the development of the expected skills.

To collect the answers, we mainly use a five-point Likert Scale [15] ranging from Strongly Agree to Strongly Disagree. Core questions of the questionnaire that we intend to use for validating our plan via a personal opinion survey are as follows:

A. The 21st Century (safety) engineer's performance will improve if he/she is able to unlearn
Strongly disagree (1)
Somewhat disagree (2)
Somewhat agree (3)
Agree (4)
Strongly agree (5)

B. If the 21st Century (safety) engineer engages in "after-event-reviews", he/she will unlearn:
Strongly disagree (1)
Somewhat disagree (2)
Somewhat agree (3)
Agree (4)
Strongly agree (5)

C. The 21st Century (safety) engineer's performance will improve if he/she will be exposed to asymmetric optionalities:
Strongly disagree (1)
Somewhat disagree (2)
Somewhat agree (3)
Agree (4)
Strongly agree (5)

D. The 21st Century (safety) engineer's performance will improve if he/she will be challenged to encouraged to adopt a barbell strategy:
Strongly disagree (1)
Somewhat disagree (2)
Somewhat agree (3)
Agree (4)
Strongly agree (5)

E. The 21st Century (safety) engineer's performance will improve if he/she is exposed to hormetic stressors
Strongly disagree (1)
Somewhat disagree (2)
Somewhat agree (3)
Agree (4)
Strongly agree (5)

V. Related Work

In the literature, various studies have built on top of Taleb's concept of antifragility in order to incorporate its principles and contribute to antifragilizing e.g., athelets, organizations, etc..

In [16], for instance, to develop specific guidelines to optimize local responses to stress and promote better adaptability of biological systems/atheletes, authors propose to use fitness profiles, obtained from an athlete's response(s) to variations in contextual conditions. They also propose to quantify the athlete's phenotypic plasticity. To do that, it is needed to identify specific behavioral (fitness) variables that support an athlete's ability to modify behavior in response to dynamic environmental conditions. The change of these variables is then measured relative to a variety of performance contexts, and the result is an ordinal fitness curve based on the response of the fitness variable at each increase in stress (i.e., adversity) or complexity.

Our work also builds on top of Taleb's concept of antifragility. However, it has a different target, it seeks to antifragilize future safety engineers mostly via the exploitation of asymmetric optionality and the barbell strategy with less emphasis on the hermetic stressors. Moreover, in addition to Taleb's antifragility-related concepts, we also borrow from the liquid modernity's metaphor and we include the development of the unlearning ability since we think that antifragility may also be developed via what we call in this paper liquid learning.

In [17], authors conceptualise the intersection between antifragility, uncertainty management, and organisational routines literatures to identify four routine archetypes that can guide actions that contribute to organisational antifragility. The identified archetypes these archetypes arise from the interplay between temporal action (as tendencies towards proactive or reactive action) and risk mitigation strategies (as preference towards redundancies or flexibilities).

Our work also includes some elements of these four archetypes since within DVA437 future safety engineers are exposed to the interplay of proactive as well as reactive dependability means. However, the conceptualization of these four archetypes is not made explicit.

VI. Conclusion

In this paper, we proposed our plan for a 21st century-oriented transformative educational change for anti-fragilizing future (safety) engineers. We also reported about the first iteration of the design of the cross-sectional personal opinion survey aimed at validating our plan.

As near term future work, we intend to complete the design of our personal opinion survey. This requires the completion of the design of the questionnaire and the design the assessment of the questionnaire itself.

As medium term future work, we intend to execute the questionnaire-based survey and based on the data collected, we will draw our lessons learned and revise our plan or proceed with its implementation.

As long-term future work, we intend to formally revise DVA437 syllabus (to reflect the findings of this explorative work) and teach the revised DVA437. In parallel, we plan to investigate the usage of hormetic stressors in context where individual training programs can be designed and appropriate instrumentations can included to reach experimental validation.

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