An Education-oriented ISO 26262 Interpretation Combined with Constructive Alignment

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Abstract

Safety standards (e.g., ISO 26262) define safety life-cycles to be adopted for the development of safety-critical systems. Professionals (i.e., safety engineers, safety managers, and, more broadly safety culture-aware personnel) who are responsible of the development of such systems can be, in turn, considered as safety-critical systems. Course-modules aimed at forming such professionals are critical. Given the criticality of such modules, the intended learning outcomes, before being constructively aligned [Biggs07] with teaching / learning / examination activities, should be derived by applying an education-oriented risk-driven process. The typical "what if" questions aimed at brainstorming on what if something goes wrong become essential to establish the expected stringency related to the knowledge and skills that personnel involved in the development of safety-critical systems should have. ISO 26262 defines a risk-driven safety life-cycle for developing safety-critical systems. In this paper, we give an education-oriented ISO 26262 interpretation and then we combine it with constructive alignment principles and we introduce SCA, Safety-critical Constructive Alignment, a new process to design Master's level safety-critical courses or modules. To illustrate SCA and its potential effectiveness, we then apply it to design a specific module.

Key-words: Safety standards, ISO 26262, Automotive Safety Integrity Levels, safety-critical systems, safety life-cycles, Education Safety Integrity Levels, education, Safety Element out of Context, Safety Educatee out of Context, Structure of Observed Learning Outocomes (SOLO) taxonomy, interactive lectures, constructive alignment.

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1. Introduction

A qualified personnel is necessary and strategic for the development of safety-critical (software) systems. The personnel and the safety-critical system constitute a safety-critical socio-technical system. Private enterprises that manufacture/supply safety-critical systems/components should promote a deep safety culture to be spread throughout all the phases of the safety life-cycle. This promotion can be performed internally (e.g., via in-house training) or out-sourced (e.g., by taking courses).

In the context of the KKS PROMPT project [PROMPT], which aims at establishing a national educational alternative targeting industry, we offer a five-module-based course (DVA433) on safety-critical software. *Safety standards* is one module within DVA433.

Given the criticality of forming such qualified personnel, current methods aimed at engineering new courses should be further developed to make sure that such criticality is taken into consideration.

Safety-critical courses are expected to make educatees transit from an (un)consciously incompetent status to a consciously safety-competent status. In this paper, first of all, we propose to equate safety-critical competences with safety-critical elements/components to be developed via course-modules aimed at forming qualified personnel, responsible of the development of safety-critical systems. Then, we build on top of our experience related to automotive safety-critical systems engineering ([Gallina13], [GRSC]) and we propose to combine corresponding best practices with best practices in courses engineering.

More specifically, to develop safety-critical courses, we propose a novel method that combines constructive alignment principles with an education-oriented interpretation of ISO 26262 main principles related to the development of safety-critical elements out of context (SEooC) to be used in context for the actual

development of safety critical systems. We call this combination SCA (Safety-critical Constructive Alignment).
We then illustrate SCA and its potential effectiveness for developing a course-module in the framework of the PROMPT project.

The rest of the paper is organized as follows. In Section 2, we provide essential background information. In Section 3 we present Safety-critical Constructive Alignment and in Section 4, we apply it. In Section 5, we discuss related work. Finally, in Section 6 we present some concluding remarks and future work.

2. Background

In this section, we present the background information on which we base our work. In particular, in Section 2.1 we provide essential information concerning constructive alignment. In Section 2.2, we briefly present the skeleton of a typical safety life-cycle for the development of SEooCs. Finally, in Section 2.3, we briefly recall the definition of socio-technical systems.

2.1 Constructive alignment

Biggs and Tang [Biggs07] propose an interesting teaching approach aimed at improving the quality of learning at the university level. Their approach is in line with the Bologna process[1] and can be synthetized with the acronym OBTL, which stands for Outcome-Based Teaching and Learning. OBTL in essence consists of the constructive alignment of:

- Intended Learning Outcomes (ILOs), which are defined as statements that stipulate the skills in terms of actions plus content (formulated via verbs plus objects), ability level (e.g. deep), and context;
- Teaching and Learning tasks, which require students to apply, invent, generate new ideas, diagnose and solve problems;
- Assessment tasks, which require students to enact the verbs that characterize the ILOs.

The necessity of the alignment stems from the recognition that to achieve intended learning outcomes the focus must be student-centered and as a consequence what the student does in terms of actions is of paramount importance. Students' actions, indeed, should mirror the skills in terms of actions that we expect students to acquire during the learning process. Since however not all students are autonomous, proactive, goal-oriented, and highly or better intrinsically motivated; teachers still have a significant role to play. Teachers thus should practice reflection or better transformative reflection allowing them to make emerge what they might be in terms of role-models in triggering students to act or better enact what is needed to achieve the intended outcomes. Transformative reflection allows teaching practices that lead to surface learning (e.g. behaviorism-oriented teaching based on punishment/premium stimulating only extrinsic motivation) to be first identified and then changed. Changes should promote the introduction of practices that make the students feel the value of the teaching material and the personal relevance (towards the development of social motivation and then gradually intrinsic motivation) as well as the chances of success/the possibility of ownership.
Teachers' actions are crucial "in setting the stage for effective learning". To encourage deep learning and thus achieve quality and not quantitative-oriented learning outcomes, teachers should be aware that their actions have an impact on the way the students' brain is activated. Teachers should succeed in triggering the activation of complex cognitive areas permitting students to exercise the actions that are part of the intended outcomes during the learning process. Coherently, the same actions should be assessed during the examination. An abstract exemplification of constructive alignment is:

- ILO: apply (expected deep ability) methods M to solve small-sized problems;
- Teaching tasks: expository lecturing + interactive lecturing aimed at providing the context that requires the students to apply the methods M;
- Learning tasks: listening to/reading material provided via expository lectures + enacting/constructively applying methods M during the interactive lectures jointly with peers/teacher(s);
- Assessment tasks: summative assessment tasks offering contexts similar to the ones proposed during the teaching tasks, aimed at requiring enactment of ILO-verb (i.e., apply methods M), possibly in non-invigilated settings but asking for personal reflections to monitor/dissuade plagiarism-oriented behaviour.

To succeed in proposing an approach towards the standardization of the outcomes, Biggs and Tang

[1] http://www.ehea.info

provide taxonomies (e.g., SOLO taxonomy) containing actions (verbs) to be used during the outcome definitions according to the kind of knowledge that we as teachers expect students to acquire. These actions should then be kept in mind to define aligned teaching/learning tasks as well as assessment tasks.
To OBTL the expression constructive alignment is associated since the intention besides the alignment is to allow students to construct their knowledge based on their experience. The constructive aspect keeps open the possibility for desirable but unintended outcomes.
As a positive side-effect their approach can be used to better formalize and standardize the outcomes at the institution level and thus allow clear and outcome-based interfaces to be defined aimed at easing students mobility as well as students integration in the job market after graduation.

2.2 ISO 26262

ISO 26262 is the functional safety standard within the automotive domain. This standard introduces Automotive-specific Safety Integrity Levels (ASIL) and a safety life-cycle that guides the system development from inception to commissioning and whose stringency can be tailored according to the ASILs. ASILs are associated to the hazardous events that, if they occur, may lead to hazards. ASILs are also associated to safety goals, which are requirements aimed at preventing the hazardous event from happening. ASILs represent confidence measures.
In this section we briefly recall the skeleton of ISO 26262 V-model-based life-cycle. The top-level left-handed safety life-cycle activity consists of the definition of the system to be developed, followed by the identification and categorization of the hazards and risk assessment procedures. Once hazards are identified (e.g., via HAZOP-HAZard and Operability- analysis), they are categorized by assigning an *ASIL,* which can assume one out of five values, ranging from negligible QM and A to D, where D represents a hazard that may lead to catastrophic consequences. An ASIL is obtained based on values assigned to three different attributes (namely, severity, exposure and controllability).
Once hazards are categorized, safety requirements aimed at reducing risk are elicited as well as traced throughout the traditional development steps (specification, design, implementation, etc.). Safety requirements are named differently with respect to the abstraction level. At the highest abstraction level (i.e., at item-level), they are named *Safety Goals*, then when the functionalities to achieve those safety goals are revealed, *Functional safety requirements* can be formulated. The formulation of the functional safety requirements concludes the *concept phase,* given is Section 3.
The following phase, called *product development phase*, given is Section 4, begins with the formulation of *Technical safety requirements* related to the architectural components aimed at implementing the Functional safety requirements. Once software as well as hardware components (onto which technical safety requirements are allocated) become clear, software as well as hardware requirements are formulated.

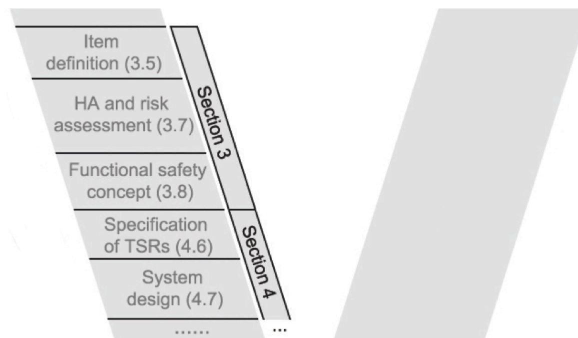

Figure 1 Portion of the ISO 26262 life-cycle

Figure 1 shows the previously textually described portion the ISO 26262 life-cycle.
On the right-hand side of the V-model, verification and validation activities are carried out to check that the elicited safety requirements are correctly specified, designed, implemented and deployed. Since these activities are not in focus within the scope of this paper, they are not detailed in Figure 1.
The novelty of ISO 26262 is also represented by the notion of *Safety Element out of Context* (SEooC)

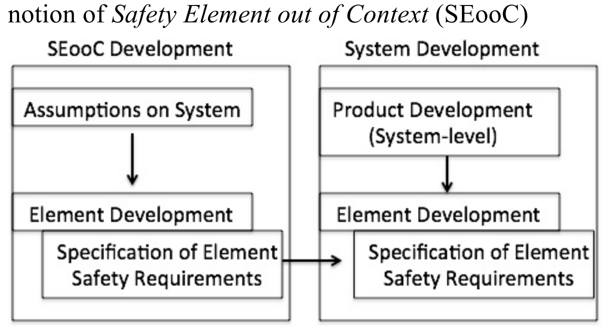

Figure 2 Reusable SEooC Development [DIS11]

A SEooC represents an element that is not developed for a specific item and thus its safety requirements are assumed during its development (SEooC development in Figure 2). Once the SEooC is developed (SEooC-related requirements specified, designed, implemented, and tested) it can be reused within a specific context to compose a system (System development in Figure 2). To be able to reuse a SEooC, assumed safety requirements should match with the actual safety requirements.

2.3 Socio-technical Systems

In this section, we briefly recall essential information on socio-technical systems aimed at enabling the reader in recognizing professionals involved in the development of safety-critical systems as part of enclosing socio-technical systems. As previously summarized by Gallina et al. [Gallina14b], socio (of people and society) and technical (of machines and technology) is combined to give socio-technical. Socio-technical refers to the interrelatedness of 'social' and 'technical' [Walker07]. Successful (or unsuccessful) system performance depends on this interrelatedness. As the SERA (Systematic Error and Risk Analysis) [Hendy03] taxonomy highlights humans may fail for various reasons including lack of training as well as absence of qualifications. A knowledge-related failure, for instance, may occur when the human does not have the pre-existing baseline knowledge or skills required to adequately or correctly interpret the situation.

Adequate training and qualification may contribute in avoiding/mitigating such failures.

3. Safety-critical Constructive Alignment

In this section, we introduce a novel approach for designing courses targeting safety-critical competences. This approach, called Safety-critical Constructive Alignment (SCA), stems from the combination of constructive alignment and ISO 26262 main principles translated in the education-oriented semantic domain. More specifically, in this section, first of all we give a motivation for the introduction of SCA; then we provide an interpretation of ISO 26262 in the semantic domain of education. Then, we combine such interpretation with constructive alignment to enable an acceptably safe formulation of Intended Learning Outcomes as well as a corresponding design of activities aimed at achieving and assessing those outcomes.

3.1 Motivation

Similarly to safety-critical systems, safety-critical competences should be developed in compliance with high-quality standards. Educatees/Employees are expected to execute crucial tasks during the life-cycle of safety-critical systems. Educatees/Employees can be seen as components/elements of an enclosing system, the socio-technical system that encloses employees, technology and regulatory/organizational procedures. Their training and qualifications are crucial to reduce certain types of failure [Hendy03]. Their training is either performed in context (e.g., within the enterprise, based on actual requirements) or out of context, based on assumed requirements. Assumed requirements (i.e., assumed intended learning outcomes) should stem from a thorough risk-driven-based requirements engineering process. Thus in Section 3.2, we interpret ISO 26262 within the education domain in order to engineer (we especially focus on the requirements and design phases) a course module aimed at forming educatees/employees that compose safety-critical socio-technical systems.

By proposing SCA, we aim at taking part to the debate [Baldwin13] around the efficacy of Bologna process' aspect concerning ILOs. More specifically, we intend to mediate and re-contextualize this aspect in our own field of practice.

3.2 From ASIL-SGs to ESIL-ILOs

In this subsection, we provide an education-oriented interpretation of ISO 26262. The idea is to translate crucial concepts in the educational semantic domain and then maintain the typical ISO 26262 process.

In particular, we are interested in introducing education-specific safety integrity levels that we call Education Safety Integrity Levels (ESIL). Similarly to ASIL, ESIL can be derived based on the severity, exposure and controllability related to the hazardous events. The hazardous events might be perceived differently according to the domain in which the employees are expected to work.

Similarly, we are interested in introducing the notion of Safety Employee/Educatee out of Context, called PROMPT-M3 SEooC, which translates the notion of Safety Element out of Context. Figure 3 builds on top of Figure 2 and shows the development of a Safety Educatee/Employee.

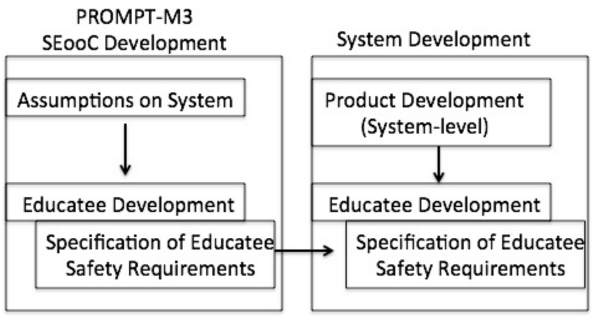

Figure 3 Reusable PROMPT-M3 Educatee Development

Safety Goals, which are ASIL classified requirements at the system level, are refined and broken down into functional/technical safety requirements (FSRs and TSRs respectively). ASIL classified TSR can be translated into ESIL-classified ILOs, more precisely into assumed ESIL-classified ILOs.

Our interpretation is limited to a few concepts, since the idea is to pioneer the application of safety standards within the education domain. An ISO 26262 expert would be certainly disappointed by this initial effort, however since ISO 26262 is currently under revision [ISO18], an in-depth interpretation would risk becoming obsolete rather soon. Moreover, a consensus has not been achieved and various interpretations are currently coexisting due to "different cultural approaches to the standard across the globe" [ISO18] Further clarifications on concepts are also expected to avoid agony while classifying hazardous events [Ellims12].

3.3 Constructively aligned ESIL-activities

Once ESIL-ILOs are formulated, teaching/learning/assessment activities have to be conceived to achieve them. These activities are aimed at design/implement the course module as well as at testing/assessing that the design/implementation meets the ILOs. Thus, constructive alignment inherently is a V-model and we customize it according to the ESIL.

4. Applying SCA to design DVA433-M3

In this section we apply SCA for designing Safety standards, the third module of DVA433. Then, we discuss our findings.

4.1 DVA433-M3

DVA433-M3 is a 1.5 credit /40 hour effort module, which at the time of writing (Spring 2015) is being offered for the first time in the framework of the PROMPT initiative. This module is supposed to be taken by personnel working in enterprises that either manufacture (or supply) safety critical (sub) systems. Bombardier Transportation, Volvo Trucks, Volvo Construction Equipment, Saab are examples of such enterprises. This module provides a panorama concerning safety standards and then focuses on safety life-cycles and development processes from various perspectives. Primarily, the module aims at forming process engineers, who have the responsibility of planning, executing and assessing safety processes for the development of safety-critical systems. The module, however, could and should be taken by those other roles that are expected to interact with process engineers. Understanding the relevance of a structured way of working via a well-defined process is the first step towards a crucial mentality change, which was also advocated by Parnas [Parnas86]: from a self-fulfilling prophecy stating that processes are not useful to a shared safety culture that spreads the relevance and potential gain of well-defined and rational-explicit processes; from a consequent tick-box mentality to a rational-based execution of (tailored) process steps.

4.2 ESIL-ILOs formulation

To formulate the ILOs and assign an ESIL, it is necessary to perform an investigation of the knowledge and skills that educates/employees are expected to offer (functional learning outcomes, after having defined the employee out of context) within the targeted safety-critical systems manufacturers/suppliers. To do that, the following questions require an answer:

- What a process engineer is expected to perform and know?
- What employees interacting with process engineers are expected to know with respect to process engineering?
- Is efficiency via intra/cross domain reuse of process elements a viable way?

By reading the standards and by interviewing industrial personnel, we realized that crucial skills and knowledge include: capability of 1) comparing/aligning safety standards and reusing process elements, 2) awareness concerning the strategic interrelatedness of roles as well as the necessity of increasing safety culture and effective communication, 3) planning, executing, and documenting processes as well as process compliance with standards. Thus the corresponding ILOs are:

• compare and contrast software safety standards;
• create a risk-based software development plan;
• apply selected process-steps;
• create typical conformance documentation.

To formulate additional ILOs (safety-related ILOs), the following questions require an answer:

- What if reuse is not systematically introduced?
- What if the relevance of a structured process is not understood?
- What if documentation does not conform to the expected requirements?
- What if an employee is not a teamplayer?

These above-formulated additional questions originate via a HAZOP analysis-like brainstorming process. From this brainstorming process, possible answers associated to these questions also originate. In particular, we realize that additional crucial skills/capabilities and knowledge include: systematizing reusable process elements, mastering process-related terminology and reference models, modeling processes, documenting process compliance, working in teams.

The ESIL to be associated to these skills and knowledge is D, the highest. Since if employees fail in guaranteeing the expected skills, catastrophic consequences may occur in terms of harm to people or environment or in terms of loss of money.

Anyway, the D level is not inherited as it is. It can be lowered (ESIL decomposition, to be performed similarly to the ASIL decomposition [ISO11] rules) if domain/context specific justifications exist. The decomposition rules are expected to customized and conceived in cooperation with industrial partners and should ease the matching between the PROMPT-M3 SEooCs and the elements that are actually needed by the industries.

4.3 ESIL-activities

To achieve the ILOs, teaching, learning and assessing activities are designed. Concerning the teaching activities, delivery of educational content aimed at supporting the achievement of all the ILOs is performed via video-recorded lectures, physical lectures, virtual learning environments and video-conferencing. Reading material, lecture notes and examples contribute in teaching the required skills.

The learning activities aimed at exercising the ILOs-related verbs consist of: contrast standards via cooperation with other attendees of other domains, plan/apply/document processes and their compliance in cooperation with other attendees.

Cooperation is highly encouraged and with respect to limited learning activities even enforced for a twofold motivation: 1) increase the chances of forming team players; 2) enable co-construction of knowledge via peer-to-peer interaction [Webb08].

Finally, concerning assessing the ILOs, students are expected to: a) reflect on the lectures via provision of pro-memoria, b) join threads of peer-to-peer discussion on virtual learning environments (more precisely via the Blackboard Learning System), c) execute a group-based project that includes tasks aligned with the ILOs, which are:

1. create a (portion of a) software development plan;
2. apply selected development/tool qualification process activities/steps;
3. create typical conformance documentation;
4. identify variation points that could be introduced to move either from standard X to standard Y (while performing 1-3) either from standard X/safety integrity Y to standard X/safety integrity Z (while performing 1-3);
5. present the work performed.

4.4 Discussion

In this section we discuss the findings related to the application of SCA for the design of M3. The discussion covers the following two main bolded aspects: **General soundness** - The application of SCA for the design of courses aimed at forming qualified personnel is sound since beyond the traditional constructive alignment permits course-designers to carefully consider safety concerns and thus has the potential to increase the quality of the formative offer. **Maturity** – SCA is still in its embryo stage. SCA is a process that combines systems/software development processes with constructive alignment, educational courses development process. SEI-CMMI [CMMI] is a process improvement approach that defines criteria to evaluate the maturity of a process. Thus, in our discussion, we use and elaborate on those criteria to evaluate SCA's maturity. SCA has the potential of being effective, but right now from a CMMI perspective its level of maturity can be considered to be in between Level-1 (Initial) and Level-2 (Managed). SCA ensures that requirements are managed and that teaching/learning/assessment activities are planned and performed to take care of functional as well as safety-related learning outcomes. However, no measurement, and control is ensured yet.

5. Related work

In the literature, various methods for designing courses have been proposed and discussed. Fink [Fink03], for instance, proposes a method for designing courses for significant learning. Fink's method differs from Biggs's constructive alignment in mainly two aspects. The first aspect is represented by the taxonomy. Instead of using the SOLO taxonomy, Fink proposes a new taxonomy called *a taxonomy of significant learning* where other dimensions are considered such has caring and human dimension. The second aspect is the consideration of situational factors e.g., characteristics of the learners as well as of the teacher.

To our knowledge, SCA represents a novelty. No related research work has explored the application of safety life-cycles within the education domain. Even tough SCA builds on top of Biggs'method, elements of the Fink's method are included via the combination of ISO 26262, which recommends situational analysis and is permeated by the caring and the human dimension via safety culture management.

6. Conclusion and Future work

In this paper, we have introduced SCA (Safecty-critical Constructive Alignment), a new process for designing courses targeting safety-critical competences. The process, which builds on top of ISO 26262 and constructive alignment principles, is aimed at offering a means for risk-driven course development. We have then applied SCA to design a course module related to Safety Standards. The illustration has been limited to the left-hand side of the ISO 26262 V-model.

Since the Swedish enterprises that expressed a concrete interest in this initiative are now well known, in the short-term future, based on the gathered experience related to the first edition, we aim at analyzing the characteristics of the various industrial contexts (avionics, automotive, railways, etc.) to identify commonalities and variabilities. Once commonalities and variabilities are identified, we combine SCA with VROOM & cC [Gallina13], our previously proposed method that aligns ISO 26262 and product line engineering practices. The idea is that since the entire set of attendees/educatees can be seen as a cross-domain product line, where the product is the educatee, commonalities and variabilities could be systematized. The combination of VROOM & cC and SCA would reduce the frequency of mismatch between assumed and actual requirements, at least for those educatees that belong to the educatee-line.

In a short-term future we also aim at elaborating a more in-depth ISO 26262 interpretation covering the left as well as the right-hand side of the V-model. Moreover, since the course is offered on-line, we are interested in applying SCA by taking into consideration the challenges that need to be faced in these circumstances to ensure an effective and safer delivery.

In the mid-term future, the idea is to perform an experimental evaluation of this new process.

Finally, in the long-term future, the intention is to explore other standards (e.g. Automotive SPICE [ASPICE10]) and see if other process elements could be considered of relevance within the education domain. To do this, a relevant starting point is the systematization of commonality and variability within safety-oriented processes, presented by Gallina et al. [Gallina12], [Gallina14a].

7. Acknowledgement

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