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# A Systems Approach to the Development of Enhanced Learning for Engineering Systems Design Analysis

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**Abstract**

This paper considers the importance of applying sound instructional systems design to the development of a learning intervention aimed at developing skills for the effective deployment of an enhanced methodology for engineering systems design analysis within a Product Development context. The leading features of the learning intervention are summarised including the content and design of a training course for senior engineering management which is central to the intervention. The importance of promoting behavioural change by fostering meaningful learning as a collaborative process is discussed. Comparison is made between the instructional design of the corporate learning intervention being developed and the systems engineering based product design process which is the subject of the intervention.

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*Keywords:* Failure Mode Avoidance: Learning Intervention; Systems Engineering, Social Constructivist Learning, Taxonomy, Learning Objectives.

## 1. Introduction

The highly competitive nature of the automotive industry with the rapid advancement of new technologies such as those associated with semi-autonomous and autonomous vehicles and ever more stringent ecological constraints results in a need to continuously upskill the product design community. The increasing complexity and ubiquitous multidisciplinary nature of systems requires evolution of design theories and methodologies (DTM). This is particularly needed to support functional integration across the different disciplinary domains with a sharp focus on handling increasingly complex requirements throughout the system's lifecycle [1]. For DTM methodologies to be effective in driving change in industry, the development of skills necessary for their effective utilisation is a key enabler. However, development and practical deployment of effective learning interventions for DTM skills is notoriously challenging: the perceived demand for fast pace new product development and introduction does not immediately provide an environment for testing, validation and adoption of enhanced, more rigorous methodologies.

This paper reflects on the experience of developing a corporate learning intervention aimed at developing skills for enhanced methodology for engineering systems design analysis and its effective deployment within a Product Development context of an automotive OEM. The requirement for enhanced design practices, underpinned by updated knowledge and skills, was pragmatically driven by the need to enhance the efficiency of Product Development, in particular to address the volume of design rework, substantiated by the large number of engineering changes made late in the design process, resulting in difficulties in meeting launch timing and inevitable cost increase. While Failure Mode Avoidance (FMA) [2] methods and tools focused on early identification of design failure modes had been introduced in the Company's design process for a long time, these were not fully integrated with the product development process (PDP) [3]. Furthermore, the effectiveness of the FMA methods was found to diminish in the face of increased systems complexity and multi-disciplinarity. An enhancement of the FMA methodology was therefore required to address (i) the need for a stronger focus on the integration of early design failure avoidance analysis


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with the complex system requirements; (ii) the need for a more effective (coherent and comprehensive) information flow in the methodology, linking functional requirements with robust design analysis and design verification methods; (iii) the effective integration of the methodology with the stage-gate PDP operated by the company. The associated requirement for training was focused on developing both technical and interpersonal skills to enable the effective and efficient deployment of the methodology in the PDP practice.

The Failure Mode Avoidance framework developed by the University of Bradford Engineering Quality Improvement Centre (BEQIC), illustrated in Figure 1 [4], was employed to underpin the enhanced FMA methodology. The strength of the BEQIC FMA framework is that it incorporates methods and tools (such as Failure Modes and Effects Analysis, FMEA) already in use within the industry, which facilitates its adoption. The key innovations of the methodology derive from its focus on a structured approach to Function Analysis; this is underpinned by the introduction of a methodology to support coherent solution independent functional reasoning, as well as a detailed interface analysis method to characterise interactions at systems interfaces and systematically capture functional requirements for system integration [5]. This facilitates an effective approach to handling the complexity of systems design, in a context where an increased amount of new technology is introduced, thus requiring a top-down analysis for systems architecture development and integration. The function failure analysis, development of robust countermeasures and robust design verification phases of the BEQIC FMA framework are strongly driven by the function analysis methodology through coherent information flow linking the supporting methods and tools.

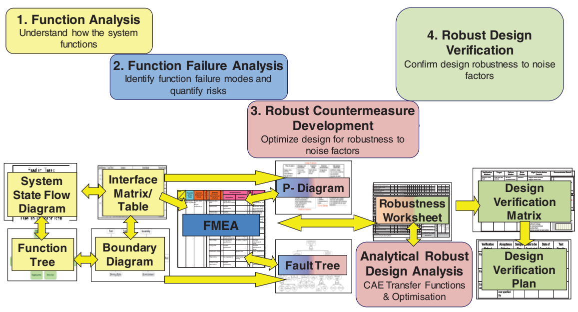


Figure 1: BEQIC FMA Framework

A customised version of this methodology was developed with Company experts experienced in extending the FMA process, and embedded into a framework referred to as SEED (Systems Engineering Excellence by Design) [6]. The effectiveness of the methodology was validated with a case study on a complex multidisciplinary automotive system (namely an exhaust aftertreatment system). An effective llearning intervention for SEED was required to support the effective deployment of the methodology within the organisation. It was recognised from the outset that the learning intervention must address both the engineering technical skills needed to implement the methodology for the engineering systems analysis and design, as well as the interpersonal skills that facilitate its effective deployment. It was also recognised that interpersonal skills play an essential role across the hierarchical levels within the PD organization. At all engineering levels, such skills are needed to facilitate the inter-disciplinary technical communication needed for system functional and structural architecting analysis, as well as ~~for~~ the adoption of revised methodologies based on methods that have been used for some time. At management levels, effective interpersonal skills are required to ensure the adherence of the methodology in the PDP, e.g. shifting to a process based paradigm in reviewing the integrity of deliverables at gateways.

This paper presents in detail the systematic instructional design approach adopted for the development of a set of learning interventions for the SEED design methodology. The instructional design framework is first considered, followed by analysis of learning requirements, and the design solution for the learning intervention. The paper ends with a reflection on the experience with the deployment of the learning intervention in the organisation.

## 2. Instructional Design Methodology/Theory

A key initial step in the design of a learning intervention is to establish a clear set of customer requirements expressed as learning objectives. Learning objectives define the expected behaviours exhibited by those who participate in the intervention i.e. describe what the learner must be able to do or perform [7] as a result of learning. Learning objectives associated with engineering will relate to tasks which range from the relatively trivial to the highly complex. To be effective, any learning intervention must give the learner the skills and knowledge to perform the complete range of tasks. To help ensure that this is the case it is useful to categorise learning objectives by degree of complexity/difficulty. A number of taxonomies of learning objectives are currently in use for such categorisation of which the most widely used are those due to Bloom [8], Biggs & Collins [9], Anderson & Krathwohl [10] and Fink [11].

Bloom's original taxonomy uses 6 hierarchical levels of cognitive learning ranging from the simplest to the most complex. Anderson & Krathwohl built upon Bloom's work with a revision to the higher learning categories and the addition of a knowledge dimension. The SOLO (Structure of Observed Learning Outcomes) developed by Biggs & Collins has 5 hierarchical levels of learning and differs from the Bloom and Anderson & Krathwohl taxonomies by being aimed at both educators and learners; this allows learners to see that their learning is due to their efforts and strategies. Fink's Taxonomy of Significant Learning has 6 interrelated major types of learning which include Human Dimension, Learning how to Learn, and Caring in addition to Foundation Knowledge and Application. Fink's taxonomy differs from the other taxonomies by being an integration of non-hierarchical dimensions.

While Fink's approach would seem to fit the SEED leaning intervention, which aims to include an element of interpersonal skills, an adaptation of the Anderson & Krathwohl taxonomy was ultimately preferred for two main