INCORPORATING A 5S STRUCTURED APPROACH TO THE PLANNING AND DELIVERING OF A FINAL YEAR DESIGN PROJECT

Denis Ring*, Jorge Oliveira

Department of Process & Chemical Engineering, University College Cork Ireland

The final year design project is a capstone, facilitating students in integrating all of their chemical engineering skills to delivering a specific body of work. In addition to the technical and scientific proficiency demanded in the development of the design solutions, students also need to address environmental and societal issues, provide marketing, business plans and analyse the economic feasibility of the investment. The ability for students to effectively cope with this multivariate task is key to a successful outcome.

The 5S management concept is originally associated with Kaizen a Japanese philosophy for achieving continuous improvement in production. A key concept of the 5S system is to empower those involved and thus embedding a real sense of project ownership. The value of students utilising such a structured approach to the formulation and development of their design project is explored. By placing their core project objective in the center and positioning the 5S engineering paradigms around this purpose will provide a methodology to continually reassess and improve the project as it progresses. In this case, however, the meaning of the "s" is different. Thus we see 5 key engineering concepts with the design goal paradigm:-

1. **Sustainability** The challenges faced are really opportunities
2. **Safety:** Embedding safety both in plant and product
3. **Soft Skills:** Innovation and leadership driving success
4. **Simulation** Facilitating technology transfer and process fitting.
5. **Sectors** Changing sectors of business operation for engineering

The incorporation of the 5S as a vehicle to promote the modern requirements of chemical engineering in design is illustrated with the experience of the design project course of the chemical engineering degree at UCC.

Keywords; 5S, design project, kaizen, sustainability, management.

**Correspondence to: D. Ring, Department of Process & Chemical Engineering, University College Cork, Ireland. E-mail: d.ring@ucc.ie*

1. INTRODUCTION

The future global employment environment will be dominated by a need to redefine what makes engineering and technology graduates successful. Traditionally, success has been defined by having “intelligent” graduates who have completed a rigorous college course that stresses problem solving and mastery of significant amounts of technical information (Roman, 2009). Design is where engineers can best display their technical mastery, their creativity and capacity for using new concepts and technologies. It will be in the teaching and application of design skills where this redefinition of the successful graduate will be most evident.

In modern business, people and organisations consider the ways in which products or services that they deliver to customers can be continuously improved. Kaizen and the 5S methodology is technique commonly used in industry to address the need for continuous improvement. The need also exists for universities to address the ways in which they can better serve their customers, both students and eventually the employers of graduates. Universities are of their very nature open and receptive to change but perhaps sometimes lack the mechanisms to build responsiveness to ongoing changes in customer’s wants and needs into their teaching.

Research into design thinking has not yet comprehensively answered questions regarding how design is done, and accordingly, there is no consensus on how it should be taught (Dym et al.,2005). The door is still open to teaching development and one possibility would be to adapt tools commonly used in an industrial setting to streamline and provide order to complex processes, namely Kaizen.

Kaizen is a Japanese word that means: “change for the better,” and is typically interpreted as implying a process of “continuous improvement.” The phrase “change for the better” implies any change that results in improvement, which could be related to quality or other factors that customers judge to be of value, such as innovation, ease of use, on-time delivery, durability, low cost, etc. (Zimmerman, 1991). To take the concept of performance to its ultimate level of simplicity, kaizen offers the "5S" steps of good housekeeping:

- **Sort:** Separate out all that is unnecessary and eliminate it.
- **Straighten:** Put essential things in order accessed.
- **Scrub:** Clean everything; tools and workplaces
- **Systematise**: Make cleaning and checking routine.
- **Standardise**: Make the previous four steps into one standard process

The Kaizen 5S process could be viewed ‘merely as housekeeping process’ but it does have a much wider potential to provide a systems approach to issues. The 5S can provide a simple structure to manage very complex tasks. The original 5S concept can be used as an allegory to an improvement of the design teaching/learning process. To achieve this one needs to identify a set of elements that do not constitute the basis of the process itself, but that provide innovative features whereby the process is improved. An extension of this concept to the final year design project is to identify 5s's that will provide step changes for improvement:-

–	**Sustainability**	The challenges faced are really opportunities
–	**Safety:**	Embedding safety both in plant and product
–	**Soft Skills:**	Innovation and leadership driving success
–	**Simulation**	Facilitating technology transfer and process fitting.
–	**Sectors**	Changing sectors of engineering business

Chemical Engineers design and operate facilities capable of manufacturing everything from baseline commodity production to complex medicines for human consumption. Most recently they have been to the forefront in the development of technologies capable of meeting major environmental issues such as carbon capture technologies. Chemical engineering design can be defined as the creation of a process and manufacturing plant to manufacture a specific material (originally this would have overwhelmingly meant chemical synthesis processes; more recently bioprocesses and emerging technologies are also considered). The range of chemical engineering designs is virtually limitless and is intrinsically linked to the modern societal needs. Final year design projects therefore provide students with their primary experience of the real world technical and political complexities.

Chemical engineering courses require students to learn and be capable of applying design skills. In the final year of the degree programme a major design project (10 ECTS is a typical requirement) is undertaken. The project reflects typical career based activities and is a team based task, usually in groups of between 3 to 6 persons, but with a strong and identifiable element of individual input and responsibility. The design project provides the ideal platform for students to acquire high level skills valued by employers and society. The Royal Academy of Engineering (2007) have identified that businesses now seek engineers with abilities and attributes in two broad areas:-

- Technical understanding
- Enabling skills.

The former comprises: a sound knowledge of disciplinary fundamentals; a strong grasp of mathematics; creativity and innovation; together with the ability to apply theory in practice. The latter is the set of abilities that enable engineers to work effectively in a business environment: communication skills; team working skills; and business awareness of the implications of engineering decisions and investments.

In addressing these goals students operate in uncharted territory, for each group the immersion into the world of chemical engineering design involves meeting multiple and interacting challenges, operating effectively as a group, and tackling not just the technical requirements of the design but also addressing the wider societal issues.

It is suggested by the IChemE (2009) that by the completion of their chemical engineering degree graduates must know and understand the importance of identifying the objectives and context of the design in terms of:

- The business requirements
- The technical requirements
- Sustainable development

- Safety, health and environmental issues
- Appreciation of public perception and concerns

2. THE APPLICATION OF 5S THINKING TO THE DESIGN PROJECT

Teaching design is not a singular task. As has been illustrated earlier the skill sets required and applied to chemical design are many and varied. Throughout the degree the student will have met a range of engineering topics in thermodynamics, heat and mass transfer, process control, among others, which will form the backbone of their design ability. It can be seen therefore that it is important to ensure that all teaching staff are part of the “design teaching philosophy” of the department or degree course.

However the final year design project is a definable and separate piece of work within the degree programme which is supported, supervised and graded. It is proper that this support would facilitate students in tackling this challenging and open-ended task by providing a structured approach to continuous improvement.

The notion of continuous improvement applies to the course (year on year module improvement) and to the specific project (month on month design improvement).

As with the application of the 5S in an industrial setting students engaging in a design task are encouraged to continually structure and order their project through the perspective of the 5S of sustainability, safety, soft skills, simulations and sectors.

2.1 Sustainability

“The challenges faced are really opportunities”

The notion of sustainability has been around for twenty years or more, it is not a tightly defined concept and means different things to different people. Recent climate change debates have given a renewed impetus to the drive for responsible developments which address the needs of triple bottom line of, social, environmental and economic. Table 1 shows the seven key areas that sustainable designs and products should address as identified by World Business Council for Sustainable Development (2001).

KEY AREAS FOR SUSTAINABLE DESIGN	IMPLICATION
1. Innovate	Novel technical and social resources – new ways to improve lives while boosting business
2. Practice eco-efficiency	Economic benefit and environmental performance
3. Move to partnerships for progress (move away from stakeholder dialogues)	Shared understanding, aligned action and social inclusion
4. Provide and inform consumer choice	A different type of demand by enhancing appreciation for values that support sustainability
5. Improve market framework conditions	A stable, corruption free, socio-economic framework that facilitates positive change
6. Establish the worth of Earth	Environmental conservation and promotion of resource efficiency
7. Make the markets work for everyone	Economic benefit and social cohesion

Table 1. Key areas of consideration for sustainable design

2.2 Safety

"Embedding safety both in plant and product"

Design is that activity where the physical artefact or a part of it, which is under design, is not currently in existence, but will be in the future. This has major implications from a safety perspective, which has been recognised in chemical engineering education for some time now. It is important that students be introduced to the concept of inherently safer design and that they realize that safety in plant operation must be considered right at the start of the design study. Process safety must be taught in a rigorous, stimulating way by staff of appropriate experience, and students now have in Design Project the possibility to practice and apply the appropriate tools (Harvey 1984).

2.3 Soft skills

"Innovation and leadership driving success"

Soft or transferable skills range from communication and team work right across to leadership and innovation. Soft skills are often critical attributes required to bridge various technical and disciplinary boundaries. As an example we see the interaction between technical expertise and its commercial exploitation at best as a fragile one. (Gupta & Wilemon,1990) suggested that products, which met their development budget but had experienced delayed launch dates generated substantially less profit than those that exceed their budget but come to market on time. In engineering, the project team is the most common form of organisation. Project teams are frequently multidisciplinary in makeup. Making project teams work efficiently and being an effective contributor are career building skills (Hall, 1990).

2.4 Simulation

"Facilitating technology transfer and process fitting"

The fact that a design outcome has yet to be built affords the possibility of representing it conceptually. The need for conceptualization in the form of a prescriptive model of some kind is obvious when the issues met are complex and design is done in an organisation. The use of process simulation is widespread. Currently, over 800 universities worldwide use the same AspenTech software as global industrial leaders including: (AspenTech, 2010)

- Top 30 petroleum companies
- Top 50 chemical companies
- 14 of the top 15 pharmaceutical companies
- 14 of the top of 16 engineering and construction companies

Process simulation is achieved using software programs designed to model process plants. Simulation is especially important in modeling systems that do not yet exist, or that would be too expensive to 'play' with. While traditionally process simulation has been associated with the large industrial plants in recent years, process simulation has been adapted by a wide range of smaller, less traditional process industries.

An example, of the versatility of process simulation and the interaction across the 5S paradigm is given by (Stefanis et al., 1995) in the study for a vinyl chloride monomer (VCM) production process. In this study the process was optimised with consideration of the global production chain. The study found that when the process was optimised for one type of pollution it often resulted in the generation of higher values of another type. Minimizing air pollution may in fact increase water pollution. When optimisation was completed for several types of pollution simultaneously, lower overall environmental impacts were achieved in the global system, not the individual system. The study also revealed that beyond a threshold value of abatement overall environmental impact could increase due to the trade-off in the impact associated with inputs versus outputs.

2.5 Sectors

“Changing sectors of business operation for engineering”

Today the chemical and related industries are in a period of rapid evolution much of it due to the unprecedented demands and constraints, stemming from public concern over environmental and safety issues.

As a consequence many of the chemical products of today and tomorrow do not have much in common with those of twenty years ago, the portfolio of skills and technical knowledge required by chemical engineers has also been changing rapidly. Chemical engineering and design practice must address this new reality.

Consider that over 14 million different molecular compounds could be synthesized in 2005. About 100,000 can be found on the market today, most of them are deliberately conceived, designed, synthesized and manufactured to meet a human need, to test an idea or to satisfy a quest for knowledge.

The development of combinatory chemical synthesis with the use of nano- and micro technology is an example of just one current industry trend. The new keywords associated with modern chemistry in the 21st century are life sciences, information and communication sciences, and instrumentation (Charpentier, 2009).

The student of today will graduate into a very dynamic employment sector, where it is increasingly difficult to be first on the market with an innovative product, and thus speeding up the product/process design development is of paramount importance. Some of the other emerging chemical engineering technological sectors include:

- BioEnergy / Green Engineering
- Biotechnology / Bioproducts,
- Clean Coal Technology / CO_2 Sequestration
- Energy / Environment
- Food Processing
- Green Technologies / Process Intensification

3. THE 5S IN THE DESIGN PROJECT OF THE BE PROCESS & CHEMICAL ENGINEERING AT UCC

The incorporation of the 5s into the teaching and learning philosophy of the final year capstone PE4010 Design Project of the BE Process & Chemical Engineering, UCC, is outlined next. In the design project students deliver one group report, and also individual design memos, which contain a detailed design of one unit operation. The real benefit of this systems approach for the students is the ability to periodically perform a 5S sweep across their design work, to in effect "clean, refocus and reorganise". Thus the somewhat daunting and amorphous task of design is rendered more achievable to the uninitiated. Table 2 illustrated the application of the 5S to the design project in UCC.

5S - STEPS	FEATURES OF DESIGN PROJECT
Sustainability	Student consider holistic design solutions and must present and defend the sustainability issues of the final design and business proposed. Is the process sustainable? If not, where are the elements of unsustainability, how could they be improved or eliminated, and what would be the cost of doing so? The objective of the "sustainability statement" is to make students reflect on the unsustainable nature that many processes do have, and assess why it is so, what are the costs and consequences of change, in anticipation for times when a much stronger emphasis on sustainability *versus* immediate costs will need to be proposed.
Safety	At a fundamental level both HAZOPs and Hazids are required, for the design memos that each student performs individually, and for the overall manufacturing process and plant laid out. This requires students to reflect on the operability and safe functioning of the various units or processes. At a more expansive level students will need to consider total lifecycle issues with respect to product plant and waste streams to insure that safety is not just a one dimensional facet of design, and integrating safety and sustainability.
Soft skills	Design begins by exploring the issues of organisational behaviour that underpin effective team work (teams and roles, personality traits, conflict orientation). Students must organise the team, plan the work, and keep track of the project evolution with recordings of meeting minutes. The team dynamics are an element of the assessment of the team's performance. The final project is presented also orally, to assist the strengthening of communication skills incorporated throughout the whole degree.
Simulation	Students are required to integrate the use of professional design software (AspenTech, or SuperPro) into their design methodologies. The design of individual unit operations (in the design memos) and of the entire process should be optimised. Students should apply the experimental design and data analysis concepts the learned elsewhere to establish the optimum combination of design choices.
Sectors	The topics of the Design Projects are not limited to conventional, traditional petrochemical products. Most are pharmaceuticals /biopharmaceuticals or innovative processes such as in the bioenergy area. These design areas are often driven by social and political change requiring cogeneration of business development plants alongside the advancement of technical issues. With novel designs much of the technical information on the specific chemicals at stake may not be easy to find, and students must consider a reasonable approach to overcome this lack of data. Many processes must also be developed out of patent descriptions, which leads students to consider with their own knowledge and creativity how a synthesis process described in a lab can be turned into an industrial scale process.

Table 2. Application the 5S structured design methodology to design projects

4. CONCLUSION

Chemical engineers are without any doubt valued as excellent problem solvers, equipped with the skills to do rigorous mathematical analysis required for design, modeling and simulation of multivariate systems. Engineering education has trained students in a systems thinking methodology, as a consequence students/graduates should have the skills and capacity of tackling both multistage and multidisciplinary tasks. These are the very engineering acumens required by society to face the global challenges of a changing social, technological and commercial dynamic. It is appropriate that students are given the opportunity to learn their engineering design skills in a measured and consistent fashion. It is also appropriate that academia be prepared to adopt practices from different cultures and professions. The 5S structured approach to engineering design will without any doubt strengthen student learning and practice. In conclusion we can see that value of organisation and continuous improvement in education is as true now as in the distant past, taking the words of the Roman philosopher Lucius Annaeus Seneca, “No man was ever wise by chance”.

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