Chapter 5

Industry 3.0 to Industry 4.0: Exploring the Transition

Shane Loughlin

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.80347

Abstract

This work is a *How-To-Guide for Digit**ALIZA**tion of Industry 4.0 Manufacturing*. It provides a novel ALIZA Canvas and ALIZA Process supported by a comprehensive ALIZA Toolset. This output is derived from observed, tangible deficiencies in contemporary functional communications in manufacturing. This study proposes an innovative approach with robust methodologies for strategic alignment of the technical and business components in manufacturing. The requirement for a supplementary educational infrastructure, to address the pronounced educational shortcomings and knowledge gaps in the transition to Industry 4.0 is outlined. An explanation is provided of how E-Cubers (our own educational organization) will design, develop, and deliver educational programmes on Topics relevant to achieving Industry 4.0 Equipment Engineering Excellence. It defines and tests the novel concept of the E-Cubers Eight Ps; encompassing **p**rioritized **p**roblem solving, via **p**ortfolios and **p**rojects, through **p**eer collaboration within a defined technology playground with emphasis on learning and **p**laying with **p**assion. The E-Cubers Eight Ps is combined with *The E-Cubers Library* to deliver a truly comprehensive specialist, national learning framework. This holistic approach will ultimately enable Ireland to lead the way in Industry 4.0 by doing what we do best *"ag spraoi agus ag imirt" (Gaelic – playing by having fun and competing)*.

Keywords: Industry 4.0 equipment, OEE, ALIZA, E-Cubers, LEGO, PBWS, OSE, DIVOM

1. Introduction

The goal of Industry 4.0 is *"The Intelligent Factory"*, which is characterized by adaptability, resource efficiency and ergonomics as well as the integration of customers and business partners in business and value processes. This *"Factory of the Future"*, will regard everything as a service (including tools and skills), it will require supply-chain integration and data availability. These combined elements will allow for the integration of the entire production process and supply chain and should, in time, enable the self-optimization of cyber-based physical systems [1].

Irish industry is currently poised for the transition from conventional automation of Industry 3.0 (I3) to the Cyber Physical Systems (CPS) of Industry 4.0 (I4). What will the transition look like? Where are the tools to manage the transition? In the absence of any definitive *How-To-Guides* business leaders depend heavily on advice from technology providers. This has the inherent risk of implementing overly technical solutions which may deliver very little business value. The primary focus for Irish businesses must be DigitALIZAtion which Gartner [2] defines as *the use of digital technologies to change a business model and provide new revenue and value-producing opportunities; it is the process of moving to a digital business*. This chapter is the *How-To-Guide for the DigitALIZAtion of I4 Manufacturing*.

Creating the *How-To-Guide for the DigitALIZAtion of I4 Manufacturing* required the research, development and validation of many novel processes and tools such as *The ALIZA Canvas, The ALIZA Process* and *The ALIZA Tools (I4-PS Scorecard, I4-ES Scorecard, The OSE Calculator and The DIVOM Benchmarking Process)*. Each of these processes and tools are explained in detail in this chapter.

For tangible business benefit is to be derived from these processes and tools they must be rapidly disseminated to practitioners. This work proposes that there is a requirement to supplement the existing education function of discipline centric qualifications with Topic centric competencies which enable the Trans-Topic collaboration necessary for the creation of novel technical solutions to the emerging Industry 4.0 business problems. This requires a supplementary educational organization, E-Cubers, which consists of a constellation of Communities of Practice (CoPs) organized around topics which are designed to facilitate collaboration and creativity for the advancement of each members individual competencies to support the achievement of I4 Equipment Engineering Excellence.

A detailed explanation is provided of how E-Cubers have utilized LEGO® TECHNIC, LEGO® MINDSTORMS and LEGO® GBC as equipment kits to deliver the Overall Equipment Effectiveness (OEE) centric BUILD, PROGRAM and INVENT methods. A detailed evaluation of Resnick's Four Ps leads to the definition of E-Cubers Eight Ps as: *E-Cubers utilize the concept of an OEE* ***P****layground to* ***P****assionately build up a* ***P****ortfolio of* ***P****rojects in collaboration with their* ***P****eers, "ag spraoi agus ag imirt" (Gaelic for* ***P****laying by having fun and competing). They demonstrate their technical ability by leveraging existing knowledge assets and creating novel solutions to the* ***P****roblems which they have* ***P****rioritized as they learn the art of their craft.*

But the work does not stop there. By creating *The E-Cubers Library* it becomes possible for E-Cubers to share their physical assets as efficiently as they utilize the Creative Commons Licensing model to share their cyber assets and knowledge. This is a truly comprehensive *How-To-Guide for the DigitALIZAtion of I4 Equipment Knowledge* which when fully harnessed will enable Ireland to take its rightful place as leaders in I4 Equipment by doing what we do best "*ag spraoi agus ag imirt.*"

2. The DigitALIZAtion of I4 manufacturing

2.1. Introduction

DigitALIZAtion which Gartner [2] defines as *the use of digital technologies to change a business model and provide new revenue and value-producing opportunities; it is the process of moving to a digital business* frequently confused with digitization which is defined as *the conversion of text, pictures, or sound into a digital form that can be processed by a computer* [3]. To minimize any risk of misinterpretation this work utilizes the term ALIZA to clearly specify the focus on DigitALIZAtion. The implementation during this study is specific to the Manufacturing sector but the ALIZA canvas, process and tools have been designed to be generic in nature and may find applications in many other domains.

The Free Model (Google, Facebook), is an excellent example of a disruptive digital business model. It disrupts the market with an *"if-you are-not-paying-for-the-product-you-are-the-product"* ethos. To achieve this business model, vendors radically migrated their primary function from *"providing excellent products"* to *"harvesting data from excellent free products"*. New digital business models in the manufacturing sector may need to be just as radical. But how will such radical changes be communicated to the complete manufacturing organization? A canvas is required on which to paint the big picture which conveys the complete transition to Digitalization; the requirement for The ALIZA Canvas emerges.

The ALIZA Canvas in isolation is not sufficient for the management of this transition. It explains the *Why, What & How* but it has no sense of *When* or *Who*. This work suggests that the *When* and *Who* is best conveyed by the utilization of a roller coaster diagram called The ALIZA Process which conveys the kinetic energy that can be provided by utilizing the appropriate tools to engage the relevant stakeholders at the correct time in the process. With the canvas and process defined the final step is to design The ALIZA Tools which will be used to benchmark and control the processes. The primary function of these tools is to benchmark and stimulate analysis to discover potential for improvements. With that in mind they must provide a scale or continuum to enable the participants to determine where they are now (Current Score) and where they want to be (Target Score). This study *"Defines"* the key Attributes for the stakeholders so that they can actively *Measure, Analyze, Improve and Control* them; providing the stakeholders with a Six Sigma process.

The methodology utilized to design the above stated ALIZA canvas, process and tools and their application to I4 Manufacturing sector is outlined detail over the following sections.

2.2. The design of the ALIZA canvas

The Eisenhower Decision Principle (EDP) has been popularized by Covey [4] in the creation of a *four quadrant Importance / Urgency Matrix* which is commonly utilized for time management. Leveraging Covey's four-quadrant approach to create *The ALIZA Canvas,* and supplementing it with a novel presentation procedure, it becomes feasible to efficiently bridge the communication gap between the primary and secondary stakeholders (Business and Technical Stakeholders in the manufacturing domain) as outlined in **Figure 1**.

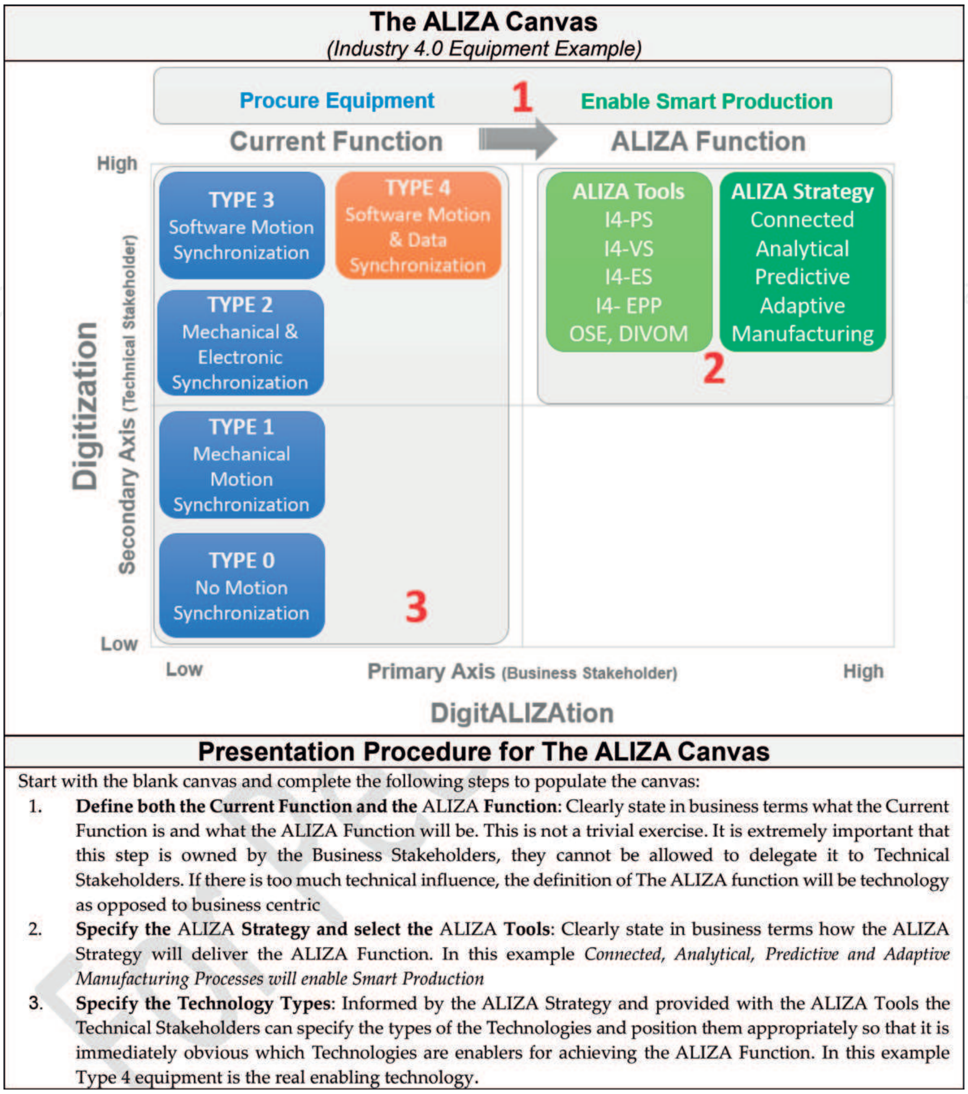


Figure 1. The ALIZA canvas and procedure for population.

The compact format of The ALIZA Canvas empowers the Business Stakeholder to rapidly communicate *The ALIZA Function*, which must be achieved by the business, how *The ALIZA Strategy*, will deliver it and *The ALIZA Tools* which will be utilized to select the appropriate technologies. The Technical Stakeholders categorize the type of digitization technologies and select the most appropriate methods of achieving *The ALIZA Function.* It paints a clear picture for all the stakeholders, without focusing on the fact that they talk extremely different languages. The adage *a picture paints a thousand words* applies.

2.3. The design of the ALIZA process

When *The ALIZA Canvas* is supplemented by *The ALIZA Process* (**Figure 2**) a true sense of *Who* must use *Which* tools at the different stages of the process becomes apparent. The roller coaster format is ideal for conveying who provides the energy is to enable the process (i.e. the Business, not the Technical Stakeholders) while the loops portray the critical requirement for collaboration between the various stakeholders at specific stages in the process.

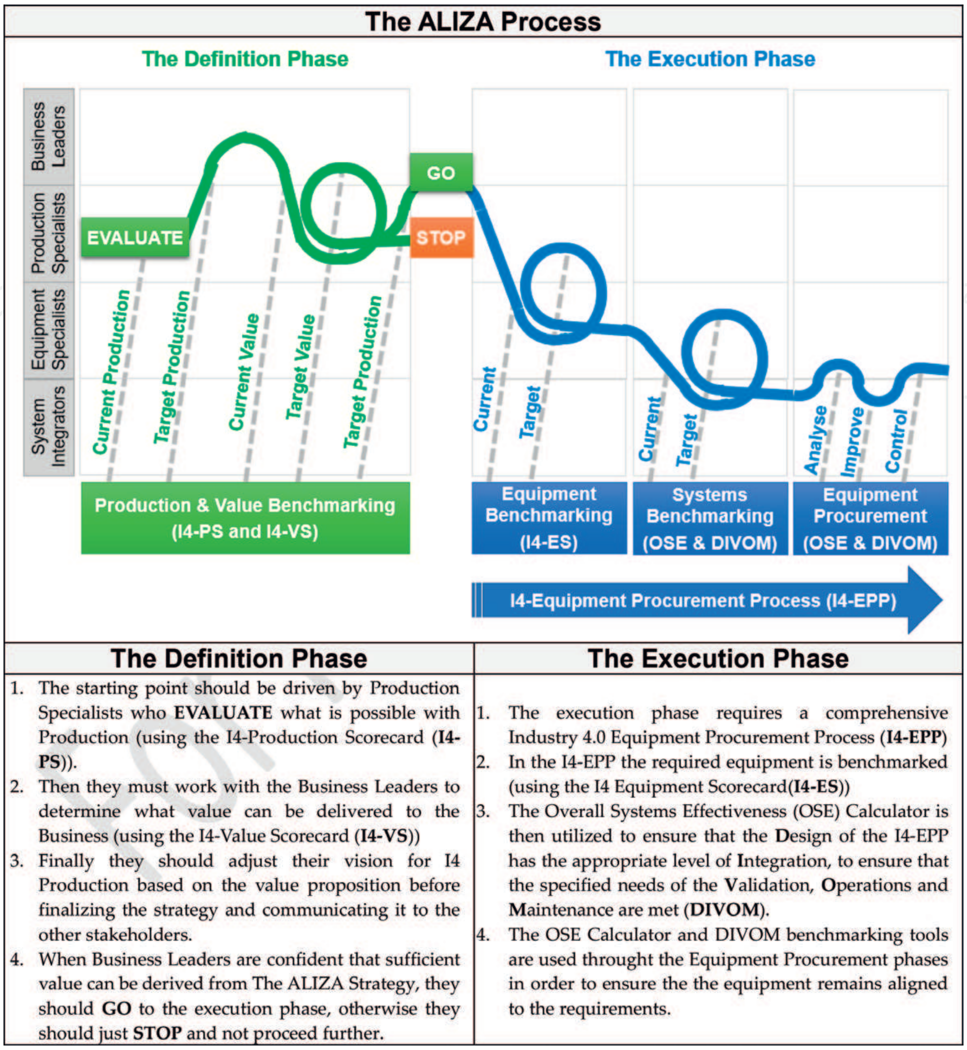


Figure 2. The ALIZA process explained.

2.4. Design of the I4 production scorecard (I4-PS)

The VDMA represents more than 3200 mostly medium-sized Companies in the capital goods industry in Germany, making it the largest Industry Association in Europe. The VDMA have produced guiding principles for the implementation of Industry 4.0 in small and medium sized businesses by utilizing *Toolbox Industry 4.0 for Production and Product* [5]. These toolboxes have valuable graphical content, but they also have an underlying process which makes them even more valuable. The Production toolbox utilizes a matrix of six functions arranged in rows and progressively more favorable status arranged in five columns. By assigning a numeric score to each column it becomes possible to create a numeric scorecard namely I4-PS Scorecard for Production. This approach also facilitates the utilization of numeric *Current* and *Target* scores to facilitate the quantification and management of improvement. A detailed analysis of the content of the I4-PS Scorecard reveals that the icons from left to right can be classified as *not connected*, *partially connected*, *fully connected*, *analyze & predict* and *adaptive* across each of the six functions contained in the rows. These classifications in conjunction with the scores assist the rapid formulation and communication of *The ALIZA Strategy* in a concise and accurate format.

2.5. Design of the I4 value scorecard (I4-VS)

Even though this work identified the requirement for an I4-VS scorecard this work did not focus on its creation. The definition of value for a Business is a specialized domain well outside the scope of this research. Generic tools such as the McKinsey Digital Compass which maps the Industry 4.0 levers to the key value drivers [6] are freely available. Each company's definition of value will almost certainly be quite different and confidential thus it very unlikely that it will be possible to provide a generic I4-VS scorecard. Based on this assumption, each organization should define its own specific I4-VS scorecard.

2.6. Design of the I4 equipment scorecard (I4-ES)

On first impressions it appeared that the VDMA's *Toolbox Industry 4.0 for Product* [5] is not relevant to this study because this study is not focused on the product which is being manufactured. The production equipment is the Original Equipment Manufacturer's (OEM) Product, so it is relevant. By assigning the same numeric score to each column it becomes possible to create a second numeric scorecard namely I4-ES Scorecard for Equipment. This approach also facilitates the utilization of *Current*, and *Target* scores to enable the quantification and management of improvement. Unfortunately, the common denominators of not *connected, partially connected, fully connected, analyze & predict* and *adaptive* which are on the I4-PS do not map directly the I4-ES. Even though it is tempting to change some of the content of the VDMA Toolboxes this has been resisted to ensure that adherence to the VDMA's best working practice is always retained. The minor embellishments proposed in these sections only assist with the usability of the tool but do not compromise the integrity of the content. It is important to note that the I4-PS and I4-ES are owned by the Business and Technical Stakeholder's respectively. This provides a very similar format of scorecard which will undoubtedly assist in bridging the gap between the two domains.

2.7. Definition of the equipment types

An in-depth review of leading assembly and packaging equipment Original Equipment Manufacturers (OEMs) revealed a common denominator; *They all transport and perform actions on the product* [7]. A review of the logic and motion technology providers also revealed a common denominator; *they all recommend the utilization of servo motors with decentralized drives synchronized via motion control networks as opposed to mechanical synchronization* [7]. But not all equipment types require motion synchronization between the transport system and stations organized around the transport system. It is perfectly valid to have equipment which operates in an asynchronous or semi-synchronous fashion. At the other extreme, there is a growing requirement to synchronize process data between the stations and transport system. Using the technologies which synchronize the transport and stations as a separator this work defined and published a novel classification method for the different Equipment Types whereby *0—No motion synchronization, 1—Mechanical motion synchronization, 2—Mechanical & electronic motion synchronization, 3—Software based motion synchronization and 4—Software based motion & data synchronization* [7].

2.8. Definition of the equipment procurement processes (EPP)

With an Industry 3.0 EPP, the mechanical discipline typically drives the process. The Information Technology (IT) and Information Systems (IS) infrastructure are not installed, simulated or tested at the OEM's premises, thus it is not possible to test many of the critical functions at Functional Acceptance Test (FAT). This results in an undesirable situation whereby many equipment defects only become apparent after the equipment is in production. Such defects are extremely expensive, and sometimes impossible, to rectify when the equipment is in production, where limited OEM support is available. These defects undoubtedly have a significant negative impact on OEE and regulatory compliance during production. This EPP is undesirable for any equipment type but it totally unsuitable for Type 3 and Type 4 and thus cannot be utilized for Industry 4.0 Equipment.

Industry 4.0 has enabled significant advances in Industrial IT, Internet based collaborative technologies and cloud computing. These advances have all but eliminated the historical infrastructural constraints which I3-EPPs were exposed to, because it is now technically possible to simulate virtually any IT or IS, in the form of an I4 Infrastructure, at the OEM's site. The provision of an Industry 4.0 infrastructure for the FAT does not, in isolation, address all the issues which have been identified during this research. The unacceptable level of software defects which exist in *custom software* [8, 9] justifies the utilization of an *Integrated Software Quality Tool* [10], which focuses on requirement risk, test and defect management during the construction of the equipment. By adding Information Technology Infrastructure Library (ITIL®) into the scope of Integrated Software Quality, a Service Desk can be provided which facilitates the efficient provision of incident, problem and change processes to manage Data-Information-Knowledge-Wisdom (DIKW) [12]. The inclusion of these tools in a novel fashion enables the creation of an I4-EPP, as outlined in **Figure 3**. This is significantly more holistic than the I3-EPP and enables the creation of a collaborative supply network "*In collaborative supply networks, OEMs will be able to offer value-added services (e.g. maintenance, upgrade) or even sell their 'products as a service'. Remote service management helps to improve*

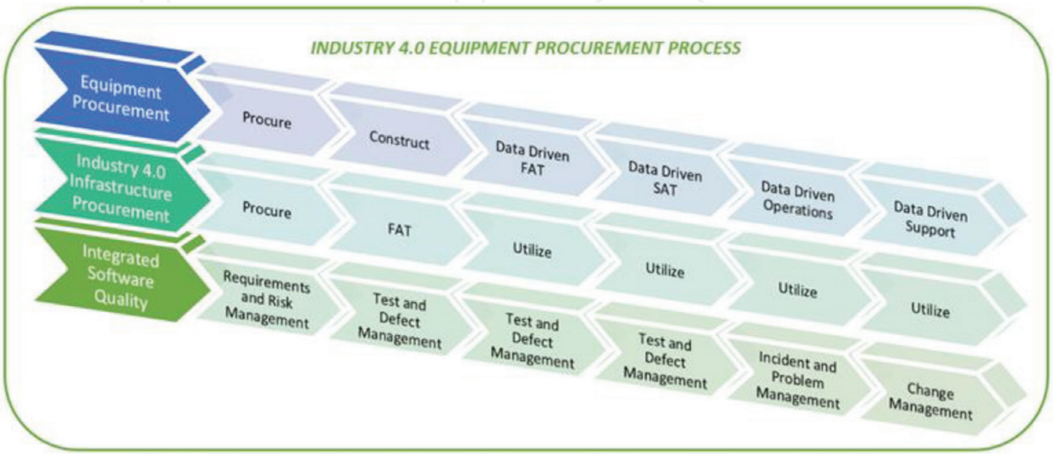


Figure 3. The Industry 4.0 equipment procurement process (I4-EPP).

equipment uptime, reduce costs for servicing (e.g. travel costs), increase service efficiency (e.g. first-visit-fix-rates) and accelerate innovation processes (e.g. remote update of device software)" [11].

2.9. Design of DIVOM and OSE

The increased complexity of Equipment Types 3 and 4 require the Concurrent Engineering approach inherent in the System Engineering process [12] to minimize costly mistakes late in the EPP. In the same way that products must be *Designed for Manufacturing and Assembly* (DFMA) [13] I4-EPPs must be designed and not simply left to chance if they are to succeed.

By applying Quality Function Deployment (QFD) [14], to the I4-EPP this study established both the high level and detailed functional requirements required to deliver the customer requirements of data driven acceptance test, excellent regulatory compliance, high OEE in production, and a fast OEE ramp. The House of Quality (HoQ) structure at the core of QFD is widely accepted by product designers, but it is a complex format and requires considerable effort to achieve an acceptable level of familiarity. This study did not consider the HoQ a suitable method of communicating the status of requirements with the various disciplines of an I4-EPP team. This study created an optimized format by taking the outputs of the QFD process and grouping the design requirements by department as follows:

> *The Project Manager is responsible for the* ***D****esign of the I4-EPP to ensure that the engineers utilize the appropriate level of* ***I****ntegration to meet the specified needs of the* ***V****alidation,* ***O****perations and* ***M****aintenance customers. There we have it;* ***DIVOM*** *for I4-EPP like we have DFMA for products.*

DIVOM provides each Department with the ability to focus on the relevant design requirements of the equipment from their departmental perspective by enabling the definition of clear boundaries of responsibility but simultaneously maintaining a concurrent, cross Department focus on the complete design requirements and I4-EPP objectives.

The design of the I4-PS and I4-ES scorecards are appealing to users because they do not; (1) have too many choices, (2) require too much thought or (3) suffer from lack of clarity. These three factors are extremely important because they all increase *cognitive load* [15] in short term memory which is only capable of holding *Seven, Plus or Minus Two Objects* [16]. The DIVOM process, which is based upon thousands of requirements, had to be broken down into several stages to achieve similar levels of *simplicity* but also must be capable of rolling up to provide an overall Key Performance Indicator (KPI) which can be easily explained and understood.

An analysis of the OEE metric concludes that the *"understandability"* of the metrics [17, 18] as opposed to its *numerical accuracy* [19, 20] has enabled it to gain widespread acceptance. The key technical metric in the DIVOM benchmarking process is the Integration metric. The integration metric focuses primarily on the cyber systems as opposed to the physical equipment. This led to the suggestion of the Overall Systems Effectiveness (OSE) metric which was defined as follows:

$$\text{OSE} = \text{Design}^{*}\ \text{Average (Integration, Validation, Operation, Maintenance)}. \quad (1)$$

This formula for the OSE proposes that the Design of the I4-EPP is the enabler for achieving the highest level of OSE and as such must have the single biggest influence. Each of the other metrics are of equal importance but will have less overall impact than the Design metric. This

http://dx.doi.org/10.5772/intechopen.80347

research is not suggesting that such a simplistic formula is capable of accurately representing every situation and it will undoubtedly require future refinement. But in its current format it leverages the lessons learned from OEE and is sufficient to provide a quantifiable benchmark metric which is fit for purpose.

A hierarchical structure and an executable application (The OSE Calculator) were developed to support the DIVOM process. The OSE Rating is at the top of the hierarchy. It is composed of five metrics (D, I, V, O and M) each with three components consisting of 10 Attributes. Attributes are composed of a variable number of requirements which are omitted from The OSE Calculator application to minimize the cognitive load on participants. It is important to note that omitting the requirements significantly increase the dependence on the facilitator.

The 10-Attribute scale is organized in order of achievement with 00 being worst to 10 being best in class. This approach has been utilized to expedite user comprehension of the measurement process. The clarity of the Attributes is further augmented by adoption of the standard color coding convention of green = low risk, orange = medium risk, red = high risk and displaying the rating graphically (see **Figure 4**).

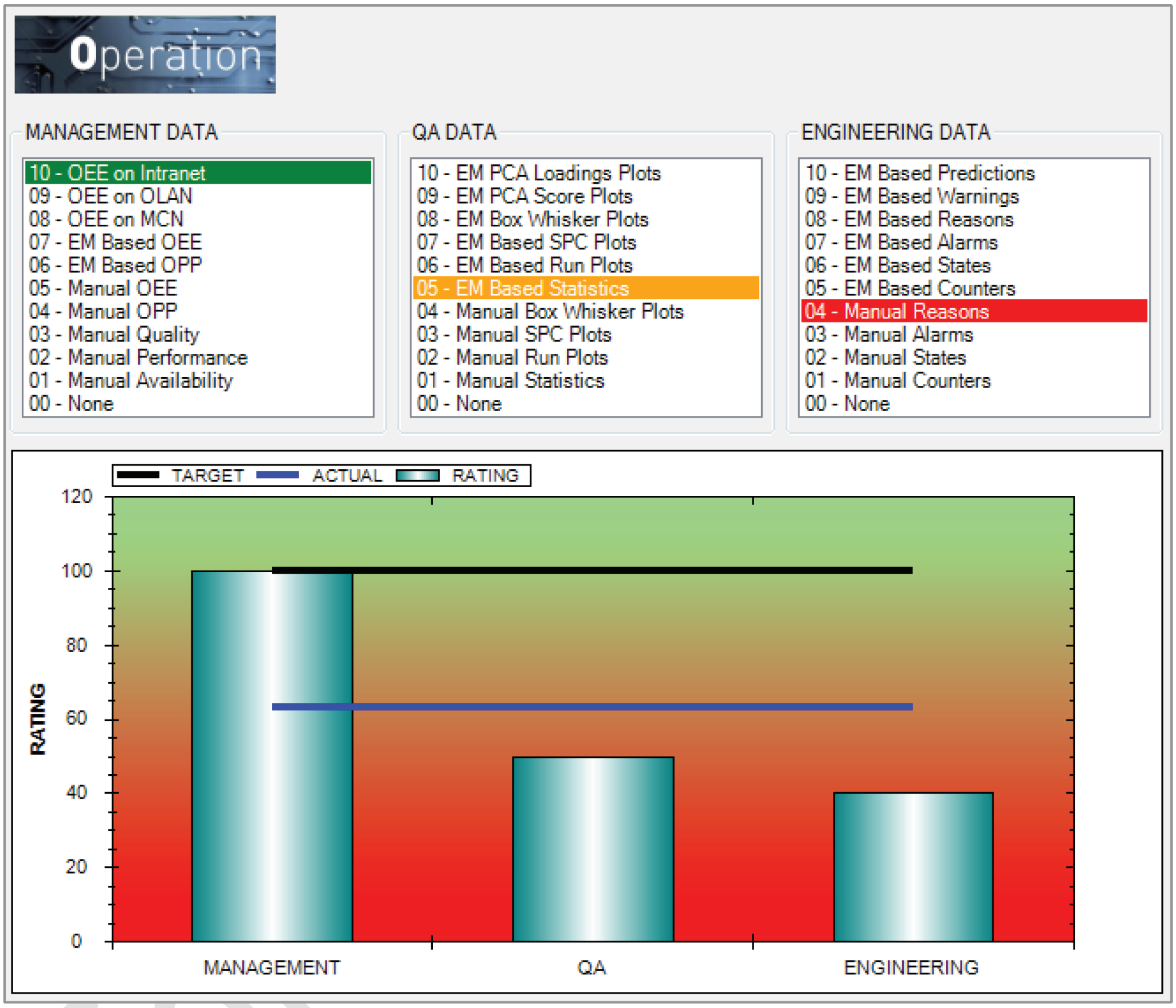


Figure 4. Design of the OSE calculator.

A three-step process was utilized with The OSE Calculator to score the metrics for the calculation of the OSE Rating; (1) Specify the ***V**alidation, **O**peration* and ***M**aintenance* customer requirements, (2) determine the appropriate level of ***I**ntegration* (3) ensure that the ***D**esign* of the EPP is correct. The metrics are evaluated by examining each component's Attributes in turn (from 00 to 10) to determine which Attributes will be achieved (see **Figure 4**).

Designing The OSE Rating and The Calculator in this fashion significantly increased the potential of conveying a large amount of specialized requirements to a general audience in an extremely short time period and providing five key metrics and an overall KPI to enable a Six Sigma approach to the EPP.

Even though the 5, 3, 10 formats of Metric, Component and Attribute creates a uniformity to reduce the cognitive load it introduces a constraint which although not immediately apparent may be problematic in some situations. The constraint is that the Attributes in The OSE Calculator may not be applicable in every situation, thus there is a requirement for the facilitator to state this as they navigate through the process. Another observation was that the participants frequently wanted to "score high". When these two items are combined they frequently attempt to utilize various justifications to claim that critical Attributes are not applicable to them. In this scenario strong leadership skills by the Facilitator are required.

3. Validation of the ALIZA tools

The experiments outlined in the following sections were conducted to validate that *The ALIZA Tools* have a suitable *"Form"* to reliably deliver the required *"Function"* and seamlessly *"Fit"* into *The ALIZA Process*.

3.1. The scorecards method

Regarding *Fit*, it is no stretch of the imagination to state that the scorecard methodology *"fits like a glove"* in the overall ALIZA process. It enables the benchmarking processes to rapidly define the current and target situations from a business perspective and utilize a relatively seamless interface to The OSE Calculator.

But the *Form* and *Function* are a totally different matter. Most of the Business Users, after a cursory initial inspection, jumped to the conclusion that the I4-PS and I4-ES scorecards are in an ideal form. The fact that the scorecards clearly outline the key metrics, which have been defined by a reputable industry organization (VDMA), the graphics are easy to understand, they have a continuum and they are measurable appealed very strongly to them. One even went so far as to declare *"Great, now we can manage Industry 4.0"*. But this work has delved a lot deeper and found issues with the function which, although not insurmountable, are not insignificant and must be addressed before widespread adoption.

An experiment was designed to validate the accuracy of these scorecards. The objective was to determine if they were *Repeatable* (the same inspector getting the same result when evaluating the same item more than once) and *Reproducible* (inspectors getting the same result when evaluating the same item) as gauges [21]. The first stage of validating the scorecards was conducted at the end of the first semester on the MEng in Mechatronics, University of Limerick, 2017. Eight students worked as a group and utilized the I4-PS and I4-ES to rate two pieces of equipment. The second stage of validating the scorecards was conducted at the end of the second semester. Four random students, who were members of the original team, were requested to utilize the I4-PS and I4-ES again to rate the same two pieces of equipment. The results were analyzed, and significant variation was observed. On the five-point scale of the scorecards the Lower Control Limit (LCL) lay close to 0 across all metrics and equipment while the Upper Control Limit (UCL) ranged between 3 and 5. Several factors such as group dynamic versus individual score, new knowledge attained, knowledge forgotten or simply confusion may have influenced these outcomes. Regardless of the root cause of the variability these results do highlight the fact that gauges which appeal to our desire to not increase our cognitive load [15] and are easy to memorize [16] in no way guarantee that they are accurate.

But all is not lost. A detailed review with the students revealed that they had significantly different interpretations of the iconography, the words simply were not descriptive enough and open to interpretation (e.g. What does" *connected"* really mean?) while many were not *mutually exclusive*. Thus, it can be concluded that with further experiments the content of the scorecards can be optimized to minimize variability and increase the accuracy to a point whereby the scorecard methods can be generally relied upon to achieve their *Function*.

3.2. The OSE calculator and DIVOM method

The first stage of the validation of The OSE Calculator and DIVOM Method focused on four industrial EPPs from 2012 to 2016. During these EPPs the researcher performed a DIVOM assessment and facilitated OSE Optimization sessions which evaluated how useful the participants found the overall tools and process. Informal interview and data capture techniques were utilized throughout these sessions.

The case studies clearly demonstrated that DIVOM benchmarking process achieved its *Function* of delivering tangible business benefits in the form of a Data Driven FAT, increased OEE and improved regulatory compliance, but with two strict provisos; the Project Sponsor must be a Change Agent focused on Industry 4.0 (Case Study 1 and 4). If the Project Sponsor is not empowered to enact change (Case Study 3) or is a diehard I3-EPP supporter (Case Study 2), then these methods are worthless and should not be utilized. Even though general awareness of I4 should have progressed since the recommendations were published [22], this work has uncovered underlying inhibiting factors which must be addressed.

Most specialists, observed during these case studies, were unwilling to gain an understating of an Attribute which they felt was not part of their primary discipline. It appears they were intimidated by having to admit that they needed to learn about these Attributes. They were *"the teachers"* not the *"students"*. They were extremely quick to disown these Attributes and assign them to other disciplines without personally gaining any knowledge. Even though it is outside the scope of this stage of the research, this reaction presents an insurmountable barrier to transdisciplinary [23] collaboration and must be better understood if I4 is to succeed in an efficient fashion.

The second stage of the validation of OSE Calculator and DIVOM Method focused on the 2016 and 2017 MEng in Mechatronics at the University of Limerick. The objective during this stage was to determine if the *Form* of the DIVOM process was suitable. A high degree of confidence had been gained from the case studies that the form of The OSE Calculator was fit for purpose in the hands of skilled facilitator, but the question which had to be answered was if others could be trained to be confident Facilitators? This stage did not focus on measuring the absolute accuracy of the student's knowledge because of the risk of bias based on association with academic grading. Instead the students were requested to estimate their own level of understanding to determine their *"confidence"* level. This assumes that any inaccuracies could be minimized based on further training if required.

The same academic format was utilized in the 2016 and 2017 classes. The students were not given access to The OSE Calculator at the outset. They were provided with the Attributes grouped by Component and Metric in a Microsoft Excel Workbook. The 2017 students were provided with a Microsoft Word Document containing explicit requirements for each Attribute at the start of the year, while the 2016 students were not provided with the explicit requirements. In the first semester the theory behind the DIVOM Metrics, Components and Attributes were explained and the students were mentored as groups to perform a DIVOM assessment on the group EPP. In the second semester they worked individually to complete the design of their solution as part of the group EPP, while in the third semester they executed the group EPP. At the end of each semester every student was requested to estimate their % understanding of each Attribute, based on the explanation that this would help to focus future lectures where the gaps in understanding existed (to mitigate the risk of students over estimating their % understanding in the hope of obtaining a higher academic grade).

All students, despite some having quite significant Industrial experience, estimated their initial understanding at close to 0%. At the end of the first semester students with access to the explicit requirements (2017) claimed to have an average of 55% understanding while those without (2016) had only 29% understanding. By the end of the second semester this gap virtually disappeared (67% for 2016 and 68% for 2017) while at the end of the third semester the 2016 group had achieved a very high 78% (2017 not finished at time of publication).

The sample size of eleven completed workbooks is too small to draw definitive conclusions from, but they are adequate to provide early indications and direct further work. Even though the DIVOM Attributes may provide an ideal framework for an expert they are extremely intimidating *Form* for novices. This may go a long way to explaining the behavior of the specialists in the case studies. Detailed requirements which further explain the Attributes rapidly increase the user's perception of their understanding of the Attributes. They are very useful for reducing the intimidation factor which was observed during the case studies.

If the detailed requirements were provided as pre-reading to the attendees of an OSE Optimization workshop it may enable them to inform themselves prior to the workshop and minimize the intimidation factor. Because these requirements are at the lower levels of

Bloom's Taxonomy [24] they could easily be tested with tools such as Moodle quizzes and the student provided with a novice level certification prior to attendance. This has the potential to create a process which transcends discipline and the collaboration issues which they cause. In this scenario the *Trans-Attribute* collaboration can be enabled where *team members must be competent enough in their own* ***Attributes*** *and understand the language of all relevant* ***Attributes*** *that enables them to contribute to the members' quality research or learning and combine various perspectives to build up a new framework* [23].

This stage of the research clearly highlights that if true understanding of the Attributes is required a significant amount of time must be invested (second and third semester) to achieve the 70-20-10 rule model [25] for learning. The dialog between a tutor and student, involving several of the common alternatives is also required to produce significantly more understanding [26] than a simplistic exposition of the correct information [27]. But that is only to be expected on the journey from Novice to Expert [28].

Regarding *Fit*, gloves normally come in pairs and The OSE Calculator and DIVOM Method is the second glove which compliments the first; the Scorecard Methodology. As with gloves, one is of limited use and the whole (The ALIZA Process) it much greater than the sum of the parts (Scorecard Methodology) + (The OSE Calculator and DIVOM Method).

4. Design of E-Cubers

4.1. Introduction

The ALIZA Canvas, Process and Tools for I4 Manufacturing Equipment represents a significant output of this work, but an educational mechanism is required to rapidly disseminate these tools and methods to derive tangible benefit of industry. This section explores conventional academic educational structures and concludes that an additional, complimentary, structure for *inventing and implement technical solutions, for business problems, in the I4 equipment domain* is required. To that end, the E-Cubers organization has been created with the following objective:

> *E-Cubers is an educational organization consisting of a constellation of Communities of Practice (CoPs) organized around topics which are designed to facilitate collaboration and creativity for the advancement of each members individual competencies to support the achievement of I4 Equipment Engineering Excellence.*

Designing and implementing a constellation of CoPs is not trivial matter. In fact, it is fraught with difficulty, but the benefits can be enormous [29]. E-Cubers are only at the start of this exciting journey of exploring how the CoPs can be organized to be truly effective Knowledge Management Systems promoting effective and productive collaboration in the Industry 4.0 Equipment domain. It should not be assumed that CoPs in isolation can guarantee the creativity required for the invention of novel solutions in Industry 4.0. But what is creativity? How can it be nurtured? By examining the applicability of Resnick's Four Ps [30] for cultivating creativity, in the general sense, and refining it to the E-Cubers specific requirements this work has defined the E-Cubers Eight Ps for cultivating creativity.

4.2. Designing E-Cubers for knowledge management & collaboration

An essential first step in designing the E-Cubers constellation of CoPs is to determine the unit of organization for each CoP. An initial reaction may be to organize by discipline or subject and adopt one of the emerging trends such as antidisciplinary collaboration [31] (more frequently referred to as Trans-Disciplinary). Unfortunately, during the execution of the DIVOM case studies this work found that the term discipline, regardless of the pre-fix, can be counterproductive for an organization such as E-Cubers. Disciplines are defined as *a branch of knowledge, typically one studied in higher education* [3]. In an academic setting disciplines are organized by Department and progression is based upon an examination and individual qualification organized around an annual academic calendar. Significant status is allocated to qualification with very little reward for collaboration. In some instances, it can be so extreme to be virtually gladiatorial in nature. For this reason, disciplines are regarded as unsuitable for the promotion of collaboration by E-Cubers and will not be used.

Wenger [29] explains that at the core of CoP there must be a shared domain which creates a sense of accountability to a body of knowledge and therefore to the development of a Practice. It is not an abstract area of interest but consists of key issues or problems that members commonly experience. It is not merely a passing issue, which can be addressed by a temporary task force. It concerns complex and long-standing issues that require sustained learning over an extended period. It is essentially a *topic—a matter dealt with in a text, discourse, or conversation* [3] as opposed to a *subject—a branch of knowledge studied or taught in a school, college, or university* [3]. The word topic has been selected as the unit for E-Cubers CoPs as opposed to domain because it evokes a more succinct and narrow focus than domain. Also, topic does not infer the requirement for examination which is assumed with the word subject.

By limiting each E-Cubers CoP to a clearly defined topic it becomes possible to define the internal structure of a CoP around the five levels of competency, namely *0—None, 1—Novice, 2—Proficient, 3—Independent, 4—Advanced, 5—Expert* [28]. Utilizing this format, individuals can easily declare their level of competence in the topic, without any risk of intimidation or feeling inadequate. Levels *4-Advanced* and *5-Expert* status is achieved based on the production of knowledge assets [28]. Experts are ideally placed to create knowledge assets which helps Novices to *"understand the language"* in an extremely short time period. This enables E-Cubers to achieve Trans-Topic collaboration on the Topic Collaboration Spectrum (see **Figure 5**). This novel approach will enable E-Cubers to achieve an unprecedented level of knowledge creation and dissemination at the topic as opposed to discipline level.

This Trans-Topic collaboration approach has the potential to create an extremely powerful evolutionary knowledge management model. Even though it is not applicable to every Topic, the rate of creation of these knowledge assets can be drastically accelerated for many Topics by organizing CoP domains around technology provider vendor Topics and leveraging their resources. This practice has gained wide acceptance in the IT domain with large technology providers such as CISCO and Microsoft's certified courses being taught by conventional academic institutions. There is no reason why this approach cannot be replicated throughout the E-Cubers constellation of CoPs.

http://dx.doi.org/10.5772/intechopen.80347

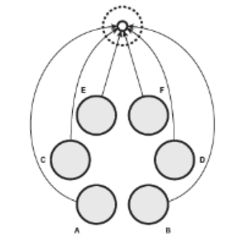
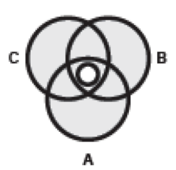
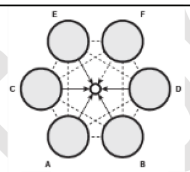
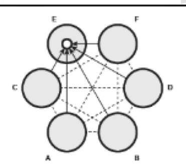
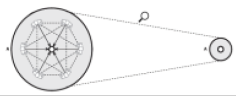
The E-Cubers Topic Collabortion Spectrum		
Trans		Trans-Topic collaboration is concerned at once with what is between, across and beyond all the domains with the goal of understanding the present world under an imperative of unity of knowledge. It begins in the white space between topics. There are no existing specialists, frameworks or methods and therefore the language and fabric of this unexplored area is still left to be defined and can be discussed on a level playing field.
Cross		Cross-Topic collaboration is concerned with the study of a problem at the intersection of multiple topics, and with the commonalities among the topics involved. Cross-Topic knowledge is that which explains aspects of one topic in terms of another. Understanding an aspect of your topic through the lens of another provides you with a wider context for the problems you are facing and hence this will refine your approach to problem-solving
Inter		Inter-Topic collaboration is concerned with the study of a problem within multiple topics, and with the transfer of methods from one topic to another the solution integrates different topic approaches and methods.
Multi		Multi-Topic collaboration is concerned with the study of a solution within one topic, with support from other topics bringing together multiple dimensions, but always in the service of the driving topic. Topic elements retain their original identity. It fosters wider knowledge, information and methods
Uni		Uni-Topic collaboration is the transfer of knowledge that occurs within the confines of a defined topic e.g. Siemens programmers working on a Programmable Logic Controller (PLC) problem

Figure 5. The E-Cubers Topic Collaboration Spectrum.

E-Cubers will utilize Office 365 for Education to manage its constellation of CoPs. This means that E-Cubers can collaborate regardless of location and organization boundaries. The correct utilization of SharePoint's CoP site templates enables a Topic-centric Knowledge Management System (KMS), which is of significantly more value for E-Cubers objectives than the discipline centric Learning Management Systems (LMS) frequently utilized by Academic Institutions. This approach facilitates a transition from the existing function of *discipline centric qualifications* to the E-Cubers ALIZA function of *topic centric competence* and an E-Cubers ALIZA strategy of *World-class equipment knowledge assets, for any E-Cuber, anywhere*. The E-Cubers constellation of CoPs facilitates, for the first time, the full collaboration spectrum from Uni-Topic the whole way to Trans-Topic to solve whatever problem is at hand in the I4 Equipment domain. Now that is a truly disruptive concept!!!

4.3. Designing E-Cubers strategies for creativity

Sir Ken Robinson, in his TED Talks on creativity outlines the importance of risk taking. He outlines that *"If you are not prepared to be wrong, you'll never come up with anything original,"* and raises the criticism that. *"We are running education systems where mistakes are the worst* *thing you can make. We are educating people out of their creative capacities."* Essentially, we are not empowering them to invent; E-Cubers must strive to reverse this trend in the I4 Equipment domain.

At school, students are taught that they must do their own work. If they leverage the work of others it is frequently seen as cheating. This is in direct conflict with the methodologies of CoPs, the open source community, creative commons and indeed general industrial practice. E-Cubers will follow in the footsteps of MIT Media Labs who despite frequent lobbying, provides an extremely strong stance of utilizing the Creative Commons License to support the concept of sharing what has already been achieved by using the remix function in MIT's Scratch environment [30]. E-Cubers will also apply the Creative Commons License to its work and utilize the everyday creativity of *little-c*, while fostering the *mini-c* inherent in the learning process during the attainment of the professional-level expertise required to practice *Pro-c*; and the expectation of the occasional *Big-C* [32]. Thus, *Big-C* is the welcome surprise but not the primary objective of E-Cubers. E-Cubers prolific creation of valuable *little-c*, *mini-c* and *Pro-c* knowledge assets will further displace the conventional misconceptions that creativity is about artistic expression, belongs to just a small section of the population, comes in a flash of light and cannot be taught [30].

Resnick [30] 4Ps methodology of *cultivating creativity through **P**rojects, **P**assion, **P**eers and **P**lay* is a truly authoritative piece of work, but this does not guarantee complete applicability in every domain. One could argue that its main strength (its general nature) which enables it to have enormous global impact when utilized at a macro scale is a significant weakness when applied at a micro level to a single organization such as E-Cubers. E-Cubers is focused on identifying and nurturing the knowledge of *Patterners* who can support I4 Equipment as opposed to catering for the *Dramatists* and the wider needs of Society. But with a *little-c* Resnick's Four P's work can be further expanded applied to E-Cubers to great effect.

Resnick [30] outlines his surprise that the Danish language unlike English has two words to distinguish between the different types of play (*spille* and *lege*). But the same is true in Gaelic, the native Irish language. In Gaelic *imir* means to play by taking part in sport or game while *spraoi* means playing to have fun. Papert has a strong aversion to *imir* and allows participants to derive their ***P**assion* from working on ***P**rojects* based around their personal interests with no boundaries. E-Cubers will instead focus on utilizing Papert's *"low floors"* to provide an easy way for novices to get started and *"high ceilings"* to allow them to work on increasingly sophisticated projects over time [33] without extending to the *"wide walls"* [30] which is too general for the specific E-Cubers objectives. E-Cubers will facilitate participants to obtain their ***P**assion* from *imir* (competing) at something which they love to *spraoi* (play) in the I4 Equipment domain. E-Cubers will practice *"ag spraoi agus ag imirt"* which translates to *"fun and play (by competing)"* in English.

I4 Equipment requires a digital twin with a representation in both the cyber and physical worlds. The cyber world is a novelty and is currently achieving enormous focus. So much so that the physical world is being somewhat neglected. If E-Cubers are to implement I4 Equipment solutions it is critical that they understand both the physical and the cyber worlds. They need to start young. The younger the better. To assist this engagement E-Cubers has created a

http://dx.doi.org/10.5772/intechopen.80347

progression sequence consisting of three distinct stages; **BUILD, PROGRAM, INVENT** which goes much further, albeit in a specific domain than purely programming centric solutions.

The **BUILD** stage utilizes LEGO® TECHNIC sets for the equipment kits. It enables participants *to "learn by playing"* by constructing the pre-designed models. It requires a strong attention to detail and organizational skills. It does not require a high level of creativity; that comes later, once the participant has grasped many of the basics. The **PROGRAM** stage utilizes LEGO® MINDSTORMS sets for the equipment kits. The participants learn about physical sensors and actuators and create programs to achieve required functions. This stage culminates in the construction the MindCub3r [34]; a piece of equipment which can solve the Rubik's Cube. The **INVENT** stage utilizes LEGO® TECHNIC sets and building instructions from PV Productions [35] for the construction of equipment based on the Great Ball Contraption (GBC). This equipment is built with standard LEGO® parts to transport LEGO® balls. It is an ideal platform for Overall Equipment Effectiveness (OEE) measurement. But it also enables two levels of invention; Equipment and Device. At the Equipment level the participant invents by creating a new design of the Equipment utilizing standard devices (LEGO® parts). At the Device level the participant invents by creating new designs of the devices utilizing freely available 3D Printing technology to rapidly manufacture them. This is true creativity at its best!!!

At the core of the OEE optimization process is the root-cause analysis of incidents to identify ***P**roblems* which must then be ***P**rioritized* to separate the vital few from the trivial many which is the essence of the Pareto Principle (even more Ps!!!). ***P**roblem* identification and ***P**rioritization* appear to have been sacrificed by Resnick for the benefit of generality, but they are key E-Cubers competencies and as such must be included. They facilitate the higher order thinking skills of analysis, synthesis and evaluation endorsed by Bloom [24] and are the starting point for the execution of the Solution based ***P**roject* which changes the design of the equipment or device to improve the OEE. This is not just *little-c* without any purpose. This is *mini-c* [32] for E-Cubers in a true *E-Cubers OEE Playground*. In the *E-Cubers OEE Playground* there is no single right or wrong answer. It is never finished. There will be a law of diminishing returns, but the OEE can virtually always be improved. Equipment such as the MindCub3r and GBCs which is capable of continuous operation are essentially *Dynamic Problem Generators* who nobody truly has the answer for. The challenge to an E-Cuber is *"Can you identify the problem, invent a solution and implement it?"* Where better for an E-Cuber to display their talents than *ag spraoi agus ag imirt* at *The E-Cubers OEE Games*? At *The E-Cubers OEE Games* the challenge is to optimize the Availability, Performance and Quality metrics of a specified piece of equipment at the three stages (**BUILD**, **PROGRAM** and **INVENT**) enabling the complete Four C Model of Creativity to be catered for [32].

4.4. Defining the E-Cubers Eight Ps

To conclude, by evaluating and expanding Resnick's Four Ps, this work defines the E-Cubers Eight Ps:

> *E-Cubers utilize the concept of an OEE **P**layground to **P**assionately build up a **P**ortfolio of **P**rojects in collaboration with their **P**eers, "ag spraoi agus ag imirt" (Gaelic for **P**laying by having fun and competing). They demonstrate their technical ability by leveraging existing knowledge assets and creating novel solutions to the **P**roblems which they have **P**rioritized as they learn the art of their craft.*

These ***P**ortfolios* enable the E-Cuber to demonstrate their capabilities to both potential employers and Academia. Who knows they may eventually be regarded as a suitable assessment method by Academia? What a different world that would be!!!

5. Applying E-Cubers to the Irish education system

The Irish education system is made up of primary, secondary and third-level education. If E-Cubers is to successfully cater for the requirements of Industry 4.0 over the long term it will need to have solutions which appeal to all three of these levels. This is a significant challenge. The promotion of a culture of collaboration and creativity across all three levels of an education system to support an emerging career has simply not been done before. The following sections outline what was discovered by applying E-Cubers at each education level.

5.1. Primary level

Several E-Cubers **BUILD** workshops were held which engaged more than 100 students between 2014 and 2018. The focus at this level was to determine if the concepts of *Equipment* with *Functions* which can be *Tested* could be imparted with" *ag spraoi agus ag imirt"* as a precursor to understanding OEE. All the workshops utilized LEGO® TECHNIC pull-back racers. They cost approximately €25, have less than 150 pieces. They take less than 30 minutes for an experienced builder to build but a novice can build them in less than 60 minutes.

A very small minority of students were clearly *Dramatists* as opposed to *Patterners* and were totally averse to following the detailed instructions. But most of the students enjoyed the build process even though less than 10% of the boys and less than 2% of the girls had played with LEGO® TECHNIC before. Without exception all the students could understand the fundamental concepts of equipment, functions and testing. But their desire for *imirt* was extremely strong. They wanted to create a competition and that is exactly what we did. We created an *E-Cubers OEE Game* based on the pull-back racers which were conducted over 300 seconds. Each team of two (who had completed the BUILD process) could test the OEE of their racer on a 2-meter-long race track with a defined start line and a defined *"landing zone"*. The three standard components of availability, performance and quality were utilized to calculate OEE and the formula was explained to the students. The performance was calculated based on the number of cycles (attempts to land in the zone), the quality was calculated based on the number of good cycles (attempts which landed in the zone) and the availability was calculated based on how many seconds during the 300 second OEE Game that the equipment was working correctly. Even though there were no prizes on offer the *imirt* really did bring ***P**assion* to the ***P**roject* as they collaborated with their ***P**eers* to get the highest OEE.

Even though the E-Cubers **BUILD** workshops were extremely successful at achieving the stated objective, several lessons which were learned which should be shared. Do not hold *"free events"* which are open to the public. There will be a significant variation in age groups and capabilities which make them virtually impossible to control. Where possible utilize the teacher to organize the workshop in their own school because they are a known authority figure and well respected by the students. Be very organized and ensure that all the sets have all the components. Get the students to do a stock-take before they start; this eliminates the *"a part is missing"* scenario. But most of all do not forget that you are *"ag spraoi agus ag imirt"* and enjoy the ***P****assion;* it truly is contagious.

5.2. Secondary level

Secondary Level (or post-primary) education consists of a three-year Junior Cycle (lower secondary), followed by a three-year Senior Cycle (upper secondary), if they take the optional Transition Year (TY). The TY is a critical decision point for young students as they decide on which potential career path to take. E-Cubers designed and implemented a week-long TY-PBWS (Project Based Work Simulation) program with the objective of introducing students to the Equipment Procurement Process (EPP) and outlining the different engineering roles within the equipment engineering team structure.

The TY-PBWS was provided to Coola (mixed-gender), Summerhill College (all-boys) and The Mercy College (all-girls) schools in 2014 and 2015 thus any gender imbalance should be negligible. During the TY-PBWS the students were organized in teams and assigned engineering roles. They had to **BUILD** complex equipment based on the LEGO® TECHNIC 8110 Unimog 400 or 42,030 VOLVO L350F Wheel Loader or the LEGO® MINDSTORMS based MindCub3r which solves the Rubik's Cube. They had to design and successfully execute a Factory Acceptance Test (FAT) and proceed to optimize the design of the equipment. All the teams clearly demonstrated that they could perform root cause analysis, in response to identified incidents. They demonstrated an ability to identify problems and suggest or implement suitable changes. Thus, it can be inferred that, with careful preparation and practical equipment examples, TY students can understand the key principles of both OEE and ITIL® in the equipment domain. 100% of the TY students stated that by taking part in the PBWS they obtained a better understanding of the various roles engineers play in the EPP and how EPPs are executed, while 95% claimed that they got a lot of satisfaction from getting the equipment working, which concurs with the *Constructionism Learning Theory* [33].

5.3. Third level BEng (honors) in mechatronics

The BEng (Honors) is at the cornerstone of the Third Level engineering education system. It typically takes 4 years to complete and results in a Level 8 award in the National Framework of Qualifications (NFQ). Following on from the success of the TY-PBWS, E-Cubers designed a 3-week-long BEng-PBWS and conducted at the IT Sligo, in July 2014. The BEng PBWS was focused on both the **BUILD** and **PROGRAM** of the MindCub3r equipment, but from a different perspective; to further analyze the problems affecting the OEE with the objective of developing and implementing solutions (**INVENT**).

During the BEng-PBWS, each student was made responsible for the software modules which fell within their individual scope. This resulted in clearly defined deliverables being achieved with the students demonstrating an ability to analyze, evaluate and create [24] solutions.

The complete team were responsible for the required integration testing which was scheduled to be completed in the third week. This enabled the mentor to accurately simulate the work environment. The team members were provided with time limited targets which they had to achieve, while being held responsible for a clearly defined role. All the students stated that they found the BEng-PBWS workshop format much more interesting, and that they learned significantly more than conventional academic lectures or tutorial-based environments. These findings strongly concur with Muller [26] and the 70-20-10 rule model for learning [36].

The BEng students went significantly further than just completing the BEng-PBWS. Under their own initiative they developed and proposed a complimentary pedagogy to augment the existing academic model. In this new model they recommended industrial engagement should occur in September and November during the first year to outline to student's what industry and employers really require. They also recommended workshops of three-week duration in June, July and August of first second and third year respectively. They advised that the third-year workshop should be competitive (*imirt*), only offered to high achievers and they should be paid a stipend during this workshop as they are mentored to identify and develop the concept of a truly significant final year project. They also requested that Industry provides them with periodic supervision during the execution of their final year project. This novel model which was proposed *"by BEng students for BEng students"* delivers more than 250 direct contact hours to students at key milestones in their development, which would significantly enhance their competencies and development.

This clearly demonstrates that skilled and motivated students at both TY and BEng levels are capable of both finding technical solutions and highlight business problems (albeit the business of providing a BEng qualification) which is extremely encouraging. It is important to note that all the participants were volunteers, they were not voluntold. This PBWS workshop was something they wanted to do. The results could have been significantly different if the PBWS method was applied to the full population or there was forced attendance.

5.4. Third level MEng in mechatronics

The MEng qualification is close to the pinnacle of the Third Level engineering education system. It typically takes two academic years to complete and results in a Level 9 award in the National Framework of Qualifications (NFQ). Following on from the success of the BEng-PBWS E-Cubers designed a three-semester-long MEng-PBWS and delivers it on the MEng in Mechatronics course at the University of Limerick since 2016. The MEng-PBWS is focused on *inventing and implement technical solutions, for business problems, in the I4 Equipment domain*. This means that the MEng applies The ALIZA Process and Tools defined in this study to industrial equipment as opposed to the LEGO® equipment (but the engineering principles are the same).

The subjects in the MEng-PBWS have been organized across three semesters. In the first semester the focus is on updating the students with the relevant standards for equipment such as ISA-S88, S95, S99, The ALIZA Canvas, The ALIZA Process and The ALIZA Tools (namely I4-PS, I4-VS, I4-EPP, The OSE Calculator and DIVOM) developed during this study. This semester provides the students with the basic vocabulary for ALIZA. In the second semester the focus is on mentoring the students to create a Solution Overview to form the basis of a project which they must deliver in the third semester. The objective is to assist the students to migrate from BEng to MEng level whereby they could both discover problems and define solutions. The results were quite surprising.

A significant number of students had virtually no interest in participating in the divergent stages of the *Double Diamond Design Process* [37]. They did not want to actively engage in the Discovery or Definition Stages. They simply wanted to be provided with the definition of the ***P****roblem* and then they would participate, ideally in isolation, in the Development and Delivery stages. They were extremely reluctant to engage with their ***P****eers* in the form group projects, ***P****assion* for the topic (the same was true with other subjects) was virtually non-existent, so the creation of a ***P****ortfolio* was a non-starter. They were extremely ***P****assionate* about obtaining the MEng qualification, the career prospects were (incorrectly in my opinion) assumed, and the topic was virtually irrelevant to them. What a shame!!!

But there were several students who were much more open to ***P****roblem* definition and ***P****rioritization* activities. These students actively ***P****layed* with the technologies. They closely collaborated with their ***P****eers* and delivered world-class solutions and collaborative ***P****rojects*, they leveraged the E-Cubers Office 365 environment and are well on the way to creating very impressive ***P****ortfolios*. They were ***P****assionate* about the topic(s) not the qualification.

Various factors such as personality types, entry grades, age profile and industrial experience were evaluated. The only metric which separated these two groups was industrial experience. But that simply appears to be an indicator of where the individual derives their motivation from as opposed to the explicit value of the experience. It appears that a BEng student who continues directly to a taught MEng, without any industrial experience, may be solely motivated by the extrinsic reward of the MEng qualification. This appears to concur with Pink [38] who outlines that *"Conventional thinking is that the higher the reward the higher the performance but once you get above rudimentary cognitive skill it is the other way around."* While the student with the industrial experience would appear to be engaged with the topic(s) and is truly motivated by *"Autonomy, Mastery and Purpose"* [38]. Basically, students with the industrial experience appear to be *volunteering to learn the topic* while the other students are *voluntold to learn the topic (to obtain the qualification)*. It all appears to center around where individuals derive their ***P****assion* from.

Does the solution lie in catering for each passion with different academic delivery models? It appears that the volunteers are not content unless they get to work on the topic(s). This is ideally suited to the apprenticeship delivery model whereby 30% of the training occurs in an academic environment but 70% of the competency is demonstrated in the working environment; they are the true practitioners of the topic(s). The voluntolds on the other hand want and must be catered for with the conventional but more collaborative academic model. While the true researchers can be catered for with the standard research model centered around very specific or a small number of topics. This enables the definition of three different roles based on the delivery model; namely *Equipment Systems Engineer, Equipment Systems Designer and Equipment Systems Researcher*. By letting the individual pick the role which matches their ***P****assion* and they can all significantly add value, in very different ways, to the E-Cuber Topic(s).

5.5. The E-Cubers library: a technical solution to a business problem

A surprising revelation during the execution of PBWS, which spanned the full educational system and crossed both genders was that only a very small number had access to the LEGO® TECHNIC and LEGO® MINDSTORMS kits. Following the PBWS more than 90% of students claimed that they would utilize LEGO® TECHNIC or LEGO® MINDSTORMS but less than 5% had access to them. Those that had access to these products personally owned them, which is quite a privileged situation because they typically cost between €100 and €300 for the larger sets. In contrast quick review of the E-Cubers kits which have been purchased for this research reveals a utilization of less than 5% (they are just sitting on a shelf not utilized for 95% of the time). This raised the question *"How can E-Cubers make their kits more generally available?"*

People are generally reluctant to lend LEGO® sets because parts will get lost or broken and then the set is useless. Well that was the case in the past, but now. With the advent of digital technologies there are catalogs of the parts in every set available [39], there are methods of utilizing 3D Printing techniques to replace some parts [40] and there are websites where individual replacement parts can be ordered [39]. All that is needed is the stock-take application and a method of providing the E-Cubers Kits to the public. E-Cubers have sponsored the development of the stock-take application and in 2018 E-Cubers in conjunction with Sligo County Library will be launching *The E-Cubers Library* to make E-Cubers Kits available to library members in Sligo. All the library members must do is stock-take the E-Cubers Kit before they check it out of the library and stock-take it again before the check it back into the library. There will be 3D Printers available to print replacement parts and a facility to order some replacement parts if required. When *The E-Cubers Library* has been fully implemented and proven in Sligo E-Cubers will make it available for all the 32 counties of Ireland so that the E-Cubers Kits can be available to any library member in Ireland.

Would not that be a significant achievement and a novel technical solution to address an urgent business problem (the emerging skills shortage for Industry 4.0 Equipment). It really is an ideal practical example of DigitALIZAtion and E-Cubers practicing what they preach. It can provide the resources for *E-Cubers OEE Playgrounds* where young people can foster their creativity *"ag spraoi agus ag imirt"* as they prepare for the *E-Cubers OEE Games*.

6. Conclusion

The presumption by many is that the challenges of Industry 4.0 will be predominantly technical in nature, but unfortunately that is not the case. The implementation of Industry 4.0 requires us as practitioners to fundamentally change the way in which we work. We must transcend our disciplines and collaborate at a topic level. But the changes go much deeper. We must also change how we educate our young people by creating supplementary environments which truly foster their creativity as well as their ability to collaborate. Only when we have made these changes will we truly unleash the powers of processes and tools such as *The ALIZA Canvas*, *The ALIZA Process* and *The ALIZA Tools* in the Industry 4.0 Manufacturing domain and in any other domain which we wish to apply them.

Author details

Shane Loughlin

Address all correspondence to: shane.loughlin@ecubers.ie

E-Cubers, IDA Industrial Park, Collooney, Co. Sligo, Ireland

References

[1] Carroll D. Factory of the Future will See Merging of Virtual and Real Worlds [Online]. 2014. Available from: http://www.engineersjournal.ie/factory-of-the-future-will-see-merging-of-virtual-and-real-worlds/ [Accessed: Aug 29, 2015]

[2] Gartner. Gartner IT Glossary [Online]. 2018. Available from: https://www.gartner.com/it-glossary/digitalization/ [Accessed: May 8, 2018]

[3] Oxford English Dictionary. Oxford English Dictionary [Online]. 2018. Available from: https://en.oxforddictionaries.com/ [Accessed: May 8, 2018]

[4] Covey SR. The 7 Habits of Highly Effective People. Free Press; 1989

[5] VDMA & Partners, editors. Guideline Industrie 4.0—Guiding Principles for the Implementation of Industrie 4.0 in Small and Medium Sized Businesses. VDMA Verlag; 2016

[6] McKinsey & Company. Manufacturing's Next Act [Online]. 2015. Available from: https://www.mckinsey.com/business-functions/operations/our-insights/manufacturings-next-act [Accessed: May 8, 2018]

[7] Loughlin S, McGrory J. A method of classifying industrial assembly and packaging equipment. In: 2013 IEEE 11th International Conference on Industrial Informatics (INDIN 2013). Bochum: IEEE; 2013

[8] CDRH, FDA. General Principles of Software Validation; Final Guidance for Industry and FDA Staff [Online]. 2002. Available from: http://www.fda.gov/RegulatoryInformation/Guidances/ucm085281.htm [Acessed: Aug 29, 2015]

[9] Martin KC, Perez A. GAMP 5 quality risk management approach. Pharmaceutical Engineering. 2008;**28**(May/June):1-7. Available from: http://www.gmp1st.com/galleries/08mj/08mj-martin.pdf

[10] Gartner. Magic Quadrant for Integrated Software Quality Suites [Online]. 2014. Available from: http://www.gartner.com/technology/reprints.do?id=1-20U6CHY&ct=140904&st=sb [Accessed: Sep 2, 2015]

[11] European Commission. Factories of the Future Multi-Annual Roadmap for The Contractual PPP under Horizon 2020 [Online]. 2013. Available from: http://effra.eu/attachments/article/129/Factories%20of%20the%20Future%202020%20Roadmap.pdf [Accessed: Sep 1, 2015]

[12] Martin JN, Bahill AT. Systems Engineering Guidebook: A Process for Developing Systems and Products. Systems Engineering Series; 1996

[13] Boothroyd Dewhurst Inc. DFMA Design for Manufacture and Assembly [Online]. 2010. Available from: http://www.dfma.com/resources/dfmawp.htm [Accessed: Aug 30, 2015]

[14] Hauser JR, Clausing D. The House of Quality. [Online]. 1998. Available from: https://hbr.org/1988/05/the-house-of-quality [Accessed: Aug 30, 2015]

[15] Sweller J. Cognitive load during problem solving: Effects on learning. Cognitive Science—A Multidisciplinary Journal. Apr 1988;**12**:257-285. Available from: https://pdfs.semanticscholar.org/d88c/481743db95687bf9d2861c16cd006f67a0a1.pdf

[16] Miller GA. The magical number seven, plus or minus two: Some limits on our capacity for processing information. Psychological Review. Mar 1956;**63**:81-97. Available from: http://www.sns.ias.edu/~tlusty/courses/InfoInBio/Papers/Miller1956.pdf

[17] Vorne Industries. The Fast Guide to OEE [Online]. 2002. Available from: http://www.vorne.com/pdf/fast-guide-to-oee.pdf [Accessed: Aug 30, 2015]

[18] Informance. Manufacturing Benchmark [Online]. 2009. Available from: http://www.informance.com/benchmarks/ [Accessed: Feb 14, 2009]

[19] Loughlin S, McFeeley G. Applying ISA 99 & ISA 88 Principles: An Often Overlooked Aspect of Manufacturing & Packaging Systems Integration. Atlanta: WBF; 2006:1-24

[20] Loughlin S. A holistic approach to overall equipment effectiveness (OEE). Computing and Control Engineering. 2003;**14**(6):37-42

[21] Pyzdek T. The Six Sigma Handbook—A Complete Guide for Green Belts, Black Belts and Managers at All Levels. New York: McGraw-Hill; 2003

[22] Acatech. Recommendations for Implementing the Strategic Initiative INDUSTRIE 4.0. Final report of the Industrie 4.0 Working Group. Acatech; 2013

[23] Stock P, Burton RJF. Defining terms for integrated (multi-inter-trans-disciplinary) sustainability research. Sustainability, 2011;**3**:1090-1113. Available from: https://pdfs.semanticscholar.org/a356/a7d8086b5d85e7804b7d25d421520562309d.pdf

[24] Anderson LW et al. A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives. Abridged ed. Pearson; 2000

[25] Lombardo MM, Eichinger RW. The Career Architect Development Planner. 3rd ed. Lominger Limited; 2001

[26] Muller DA. Designing effective multimedia for physics education [online] (PhD thesis). 2008. Available from: http://www.physics.usyd.edu.au/super/theses/PhD(Muller).pdf [Accessed: Aug 1, 2014]

[27] The Kahn Academy. Kahn Academy. [Online]. 2018. Available from: https://www.khanacademy.org/about [Accessed: May 8, 2018]

[28] Engineers Ireland. CPD Accredited Employer Standard Support Guide. Dublin: Engineers Ireland; 2001

[29] Wenger E, McDermott R, Synder WM. Cultivating Communities of Practice: A Guide to Managing Knowledge. Harvard Business School Press; 2002

[30] Resnick M. Lifelong Kindergarten, Cultivating Creativity through Projects, Passion, Peers and Play. London: The MIT Press; 2017

[31] Ito J. Antidisciplinary [Online]. 2014. Available from: https://joi.ito.com/weblog/2014/10/02/antidisciplinar.html [Accessed: May 8, 2018]

[32] Kaufman JC, Beghetto RA. Beyond big and little: The four c model of creativity. Review of General Psychology. 2009;**13**:1-12. Available from: https://pdfs.semanticscholar.org/f4fc/c5125a4eb702cdff0af421e500433fbe9a16.pdf

[33] Papert SA. Mindstorms: Children, Computers and Powerful Ideas. The Perseus Book Group; 1993

[34] Gilday D. How to build MindCub3r for LEGO MINDSTORMS EV3 [Online]. 2013. Available from: http://mindcuber.com/mindcub3r/mindcub3r.html [Accessed: May 8, 2018]

[35] PV Productions. What's a LEGO GBC? [Online]. 2018. Available from: https://pv-productions.com/whats-a-lego-gbc/ [Accessed: May 8, 2018]

[36] European Commission. European Business Forum on Vocational Training—Report from Workshop 3: The Use of Work Based Learning for Competence Development—Challenges and Practices [Online]. 2012. Available from: http://ec.europa.eu/education/vocational-education/doc/forum12/sumw3_en.pdf [Accessed: Dec 19, 2013]

[37] The Design Council. The 'Double Diamond' Design Process Model [Online]. 2008. Available from: http://webarchive.nationalarchives.gov.uk/20080821071133http://www.designcouncil.org.uk/en/About-Design/managingdesign/The-Study-of-the-Design-Process/ [Accessed: May 8, 2018]

[38] Pink DH. Drive: The Surprising Truth about What Motivates Us. Riverhead Books; 2009

[39] Rebrickable. Rebrickable [Online]. 2018. Available from: https://rebrickable.com [Accessed: May 8, 2018]

[40] PrintABrick. PrintABrick [Online]. 2017. Available from: https://printabrick.org/ [Accessed: May 8, 2018]