# 3D Alignment in the Adaptive Software Engineering Curriculum

Ciarán O'Leary, Deirdre Lawless, Damian Gordon, Dave Carroll, Fred Mtenzi, Michael Collins
Dublin Institute of Technology, School of Computing, Kevin St., Dublin 8, Ireland
{ciaran.oleary, deirdre.lawless, damian.gordon, dave.carroll, fred.mtenzi, michael.collins}@comp.dit.ie

*Abstract* – **The Emersion education model was designed by embracing experience from industry and academia in Ireland, the UK and China. A significant part of the model is a curriculum for an honours degree programme in Computer Science to be delivered in the Harbin Institute of Technology, China. Elements of the curriculum are strongly aligned in three ways: *constructively*, *horizontally* and *vertically*. Constructive alignment is the well accepted approach to curriculum design which emphasises that learning, teaching and assessment must be aligned with the learning outcomes of all components of the programme. Horizontal alignment of elements requires the student to transfer problem solving knowledge between domains at the same stage of the programme. Vertical alignment requires that elements are structured to build on foundational knowledge and provide a platform for future elements. When combined, the three dimensions of alignment guide the curriculum development process. Our 3D aligned curriculum demonstrates how components interlink at various layers in a hierarchy to support the development of both the technical and transferrable skills required by the software industry in China and elsewhere.**

*Index Terms* – Curriculum Design, Constructive Alignment, Transnational Co-operation, Diversity.

## INTRODUCTION

Alignment of elements within the curricula of third level education programmes is widely accepted as essential for facilitating successful student learning [1]. Biggs theory of *constructive alignment* [2] informs much modern research and development work in curriculum design, by recognising the inter-relationships between *learning outcomes* (the statement of *functioning knowledge* and *declarative knowledge* the student will be equipped with upon completion of a programme or module), *learning and teaching methods* (those methods that will be used to provide the student with that knowledge) and *assessment methods* (measuring the degree to which the student can satisfy the learning outcomes).

This paper introduces *3D Alignment*, a new model that supports a curriculum where elements (any of the component parts of a curriculum, including *modules*, *learning and teaching methods*, *assessment methods* etc.) adapt in response to changes in other elements. We describe how the model was used in the development of a Software Engineering curriculum for the Harbin Institute of Technology (HIT), China.

## ALIGNMENT

In general, we consider *alignment* in the curriculum to be that which guides and constrains both the design of the curriculum and its subsequent delivery. Alignment occurs at many levels, including but not restricted to, those listed here:

- Needs of academia with the needs of industry.
- Output of the university with the needs of industry in the short-term and long-term.
- University environment with teaching, learning and assessment methods.
- Cultural environment with teaching, learning and assessment methods [3].
- Programme learning outcomes with teaching, learning and assessment methods.
- Stage learning outcomes with preceding and succeeding stage learning outcomes.
- Module learning outcomes with stage learning outcomes.
- Module learning outcomes with other modules at the same stage.
- Module teaching, learning and assessment with other modules at the same stage.
- Module learning outcomes with other modules at preceding and succeeding stages.
- Module teaching, learning and assessment with other modules at preceding and succeeding stages.

The development process described here grouped those forms of alignment into a model which we term *3D Alignment*. This model stresses the need to consider alignment in terms of inputs, outputs and internal relationships, along *constructive*, *horizontal* and *vertical* dimensions, as shown in Figure 1.

Many instructors consider implementing novel and interesting learning techniques in the delivery of their modules. Active learning [4], problem based learning [5], service learning [6] and many others are tools which benefit the student, it is suggested, by creating learning experiences that contrast with the traditional lecture format. According to both our experience and the published literature [4], these learning experiences are quite powerful in improving student's knowledge retention and skill development. However, in an aligned curriculum, we argue, methods employed in any aspect of the curriculum have, of necessity, a cascading effect on all other part of the curriculum, something which must be captured and embraced.

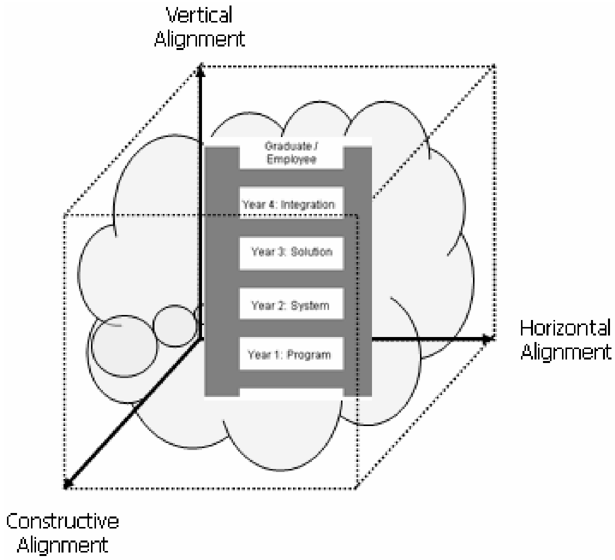


FIGURE 1
3D ALIGNED CURRICULUM DESIGN

We, like others, consider it necessary to recognise the dynamic nature of the curriculum. Where inputs, outputs and processes change over time, the elements of the curriculum must also change. In this regard, the definition, documentation and distribution of the curriculum must only be considered a feature on the landscape of the overall lifetime of the curriculum. It is vital that members of the team delivering the curriculum co-operate across modules or elements of the curriculum. It is also vital that during the curriculum development process, those writing the curriculum appreciate that it must be flexible to change when any aspect of the environment changes. The goal of alignment is to identify the effects that changes have.

Our 3D alignment model was designed to meet these requirements, and was implemented in the development of the Emersion curriculum. The resulting curriculum is comprised of two parts:

- *Curriculum core*: A standard curriculum, resiliant to the environment in which it is delivered. At this stage we identify how each element is aligned with other elements and external factors.
- *Curriculum implementation*: An implementation of the curriculum core for HIT in China. We will demonstrate how the implementation environment forces a modification of many aspects of the curriculum.

Designing curricula that apply globally rather than just locally adds to the worldwide body of knowledge. By identifying those factors that make the implementation of a curriculum locally unique, one is also stating how the curriculum can be adapted for implementation in other locations. This has the combined benefits of extending the lifetime of the curriculum locally, and contributing to curriculum development efforts worldwide.

## EMERSION

During the 1990s, Ireland underwent a major economic transformation [7] developing into one of the world's leading software industries [8], [9]. Central to Ireland's success were its telecommunications infrastructure and its flexible, well-educated graduates who can be integrated rapidly into the workforce [8]. Ireland's educational institutes played a major role in Ireland's transformation. The Dublin Institute of Technology (DIT) has a recognised excellence in producing industry-oriented graduates who have contributed greatly to the recent Irish economic success [10].

China's education system is internationally recognised as being extremely successful in producing graduates from Computer Science degree programmes who can demonstrate high levels of academic excellence [11]. Many graduates in the system progress to post-graduate education where they engage in cutting edge research and development, with high numbers of students graduating at PhD level in Computer Science and related fields [12]. While many multinational organisations such as IBM and Microsoft have established research centres in China, there is growing concern that there are insufficient software engineers available to operate productively in the rapidly developing Chinese software industry.

In 2003 it was estimated that 500,000 software engineers were required by China but educational institutes could only supply 100,000 [13]. Not only was the quantity produced insufficient but there was general consensus among both industry and educational experts that the quality of these graduates was also insufficient [11]. While academic excellence is accepted, the concern of government policymakers and employers lies in the fact that the excellence appears to be confined mainly to theoretical excellence, to the detriment of the practical skills immediately required to develop the software industry.

Recognising this, the Chinese Ministry of Education established 35 National Pilot Schools of Software (NPSS), one of which is hosted by the Harbin Institute of Technology (HIT), a top ten university in China. The aim of these schools is to produce Computer Science and Software Engineering graduates with the knowledge, skills and experience necessary to become rapidly productive in the Chinese software industry. Recognising Ireland's recent emergence as a significant participant in the global software industry, the NPSS at HIT established close links with the School of Computing at the DIT, the largest third level education provider in Ireland.

In addition to pre-existing collaborative projects, the Emersion (**E**ducation to **ME**et the **R**equirements of **S**oftware **I**ndustry and Bey**ON**d - Establishing, Implementing and Evaluating an Industry-Oriented Education Model in China) project was established in 2003. The aim of the three year project was to establish, implement and evaluate an education model with an industrial ethos to deliver sustainable, high-quality, effective IT education in China both now and in the future as well as fostering stronger relations between the EU and China. With the *Dublin Institute of Technology* (DIT) as

lead partner, the project also involved HIT in China and the *University of Wolverhampton* (UOW) in the United Kingdom.

Emersion's overriding goal was to harness the skills and experience of DIT and UOW to develop an education model for China incorporating a quality assurance system and a curriculum ready for implementation in China immediately, and adaptable for future requirements. In return, HIT's recognised strengths in Computer Science research would be called upon to inform, direct and develop Computer Science research in DIT and UOW.

## CURRICULUM DEVELOPMENT PROCESS

Input to the curriculum development process was required from a diverse set of interested parties, including DIT and UOW as education providers in the EU; the software industry in the EU; HIT as an education provider in China; the software industry in China; and published best practice in industry oriented curriculum development (CC2004 [14] and SWEBOK [15]).

The development process began by establishing communication links between all partners. As well as occasional face to face meetings between the Emersion partners (DIT, HIT, UOW), ongoing communication took place through ICT (Information and Communications Technology) tools such as e-mail and the Moodle Virtual Learning Environment [16]. As development of the curriculum commenced, all documentation was put online as editable Wiki pages at DIT [17].

Input from industry was solicited by means of surveys and questionnaires presented to industry representatives in each of the partner countries. In addition, consultation with industry in Ireland took place through a number of meetings with representatives of organisations with whom DIT had established links. Most of these organisations are active in the software industry not just within Ireland, but globally.

## CURRICULUM CORE

The curriculum core was designed to meet the following requirements, which were formalized through *vertical*, *horizontal* and *constructive* alignment.

- It must define the learning outcomes, learning and teaching methods, assessment methods and content for a general industry oriented software engineering undergraduate degree programme.
- It must identify the relationships between elements of the curriculum, to identify how changes in these elements impact upon other elements.
- It must identify the relationships between elements of the curriculum and external factors such as the university environment and the cultural environment, and state how changes in these factors impact upon the curriculum core.

### *I. Vertical Alignment*

Vertical alignment stresses the need for elements within the curriculum (where elements include learning outcomes, learning and teaching methods, assessment methods, modules and stages) to be aligned with those elements that precede and succeed them. In this regard, we are primarily concerned with:

- The student intake to a programme that is run using the curriculum. We are concerned with the educational and cultural background of the students. Stating these in the same form as learning outcomes is most useful, as it ensures consistency with the remainder of the curriculum.
- The alignment of learning outcomes at each stage of the curriculum with the learning outcomes from previous and following stages. We feel it is important to clearly state learning outcomes at specific checkpoints throughout the curriculum, so we can identify what a student will be able to do at specific points. This should be done independently of the modules at the stages, as some learning outcomes require attention from more than one module in order to be learned and assessed. Learning outcomes for a stage should be stated with the assumption that earlier learning outcomes can be re-learned or re-assessed. What is new at each stage is the way in which a learning outcome is demonstrated, as knowledge develops, as per Bloom's Taxonomy [18].
- The alignment of learning and teaching methods at each stage of the curriculum with the learning outcomes from previous and following stages. Once again, if we consider certain learning and teaching methods to be applicable to a stage of the curriculum rather than to specific modules, we can identify these methods, and show how they relate to the learning and teaching methods from other stages. For example, methods can be employed which give the student a different environment in which to revisit material learned previously. Where students may have received lectures on a specific topic at one stage, requiring them to make presentations on the same topic (or a topic which incorporates the earlier topic) at a later stage can result in their examining the material from a different perspective, thus further developing their skills.
- The alignment of assessment methods at each stage of the curriculum with the assessment methods from previous and following stages. As students progress through the curriculum it is important that they be reassessed on material presented earlier. It is vital for a domain such as Software Engineering that students develop their skills as practitioners as the programme progresses – therefore, at the latter stages it is more important to assess the student's functioning knowledge, in particular in settings which are similar to the industrial environment for which they are being prepared.
- Modules belonging to particular logical streams throughout the curriculum (software development, databases etc.) should be aligned closely with each other. Although learning outcomes and all methods should be captured at the level of stage, finer grained alignment can also be achieved by examining the requirements and outcomes of individual modules.

- The expectations of industry. As graduates are being prepared for industry, the needs and demands of industry in the short- and long-term must be factored into the curriculum. The main feedback we received from our industry surveys was that while technical and transferable skills are vital in the short-term, for continued success and progression, students need to be able to independently develop their own skill set and knowledge. Reflective practice [19] and lifelong learning must be key considerations of the curriculum.
- The requirements for postgraduate study. Increasingly, industry requires employees with advanced qualifications. Similarly, universities require students who are prepared for postgraduate study. The entry requirements for such programmes must be aligned with the learning outcomes of the programme.

*II. Horizontal Alignment*

After formally recognising stages of the curriculum, and stating what the student will be able to do upon completion of a stage (learning outcomes), how they will learn those skills (learning and teaching methods) and how we will know that they have those skills (assessment methods), we are presented with the task of determining on a micro level how those outcomes and methods will be divided between individual modules at each stage. We must also examine the external factors that constrain and enhance each stage, and update our curriculum with these in consideration. For horizontal alignment, therefore, we are mainly concerned with:

- The learning outcomes of the modules at each stage. The level of detail provided in the module learning outcomes will be greater than the learning outcomes for the stage, but each learning outcome must be mapped to a learning outcome for that stage. Importantly, some stage learning outcomes may not be specifically applicable to an individual module, but may require co-operation from multiple modules. Also, some stage learning outcomes may be addressed in many modules, and others may require agreement from the implementation team on which module will assess particular learning outcomes (e.g. presentation skills).
- Learning and teaching methods within the stage. Learning activities which span multiple modules at the same stage should be encouraged. Large projects, typical in service learning and other forms of active learning, require co-operation across many modules. Also, given the importance of industrial involvement, guest seminars from industry representatives, case studies and field trips should be incorporated across modules to avoid fragmentation of student knowledge, and encourage students to transfer learning between domains.
- Assessment methods within the stage. In our experience, joint assessment across modules is a matter of some contention for many educators. Where there is a requirement for students to pass individual modules, these modules are typically assessed independently. There is a widely held view that anything which is not assessed will not be learned [1]. Whatever the veracity of this view, it seems clear that if learning activities across multiple modules are employed and assessment is not distributed accordingly, then the student may not acquire the skills required to transfer knowledge between domains.
- The learning environment. The learning and teaching activities and assessment methods employed are constrained by the availability of resources such as personnel, facilities and tools.
- The cultural environment. Certain activities and methods are more applicable in environments where independent learning is stressed from childhood. Often team based work and group work are regarded with apprehension.

*III. Constructive Alignment*

Constructive alignment [2] is the popular view that learning outcomes, assessment methods and learning and teaching methods are interlinked and interdependent. Central to the theory behind constructive alignment is the need for adaptation. As the curriculum is implemented, new unintended learning outcomes emerge as a by product of the learning, teaching and assessment methods employed. Reflection is required by the teaching team to capture both these emergences and any shortcomings of the curriculum.

As educators, we are familiar with the idea of an adaptive curriculum. We have observed on numerous occasions how intended learning outcomes are not met, or how emergent learning outcomes are demonstrated by students. We, like many others, have also seen how changes in external factors such as the quality of the intake, the availability of resources, and the background of the students have impacted upon the methods used in teaching.

As computer scientists, we also recognise that the curriculum, like any other adaptive system, can be modeled to some degree. Our 3D Alignment model attempts to capture the complex inter-relationships between elements within the curriculum so that when changes occur in any internal or external factors, we can begin to examine the impact it has throughout the curriculum.

The role of the teaching team is central to this adaptivity. Interaction and cooperation between all those involved in the curriculum is vital for ongoing development. A careful balance needs to be achieved in the definition of the curriculum to allow for modification where necessary, but also provide sufficient direction to both the staff and students who use the curriculum document for direction.

*IV. Overview of the Curriculum Core*

Figures 2 and 3 below were designed to illustrate our central concerns in compiling the curriculum core.

Figure 2 demonstrates the need for the curriculum to provide the student with the fundamental skills required for the area, with all subsequent and additional material addressing the need for key technical and transferable skills, informed by the cultural ethos and facilitated by industrial involvement.

Figure 3 depicts a ladder of achievement, intended to highlight the primary learning outcome for each stage, coupled with the learning and teaching methods and summative (contributing to a grade) assessment methods. The formative (not used in grading, only for monitoring progress) assessment methods feed directly from the learning and teaching methods. When combined, these figures illustrate a type of curriculum that encourages active forms of learning, but recognises the need for examinations to assess fundamental knowledge in the area. At the early stages of third level, students are most accustomed with this form of assessment – it is felt that the best approach is to slowly direct the student to more practical assessment throughout their education, using formative assessment to improve their practical skills.

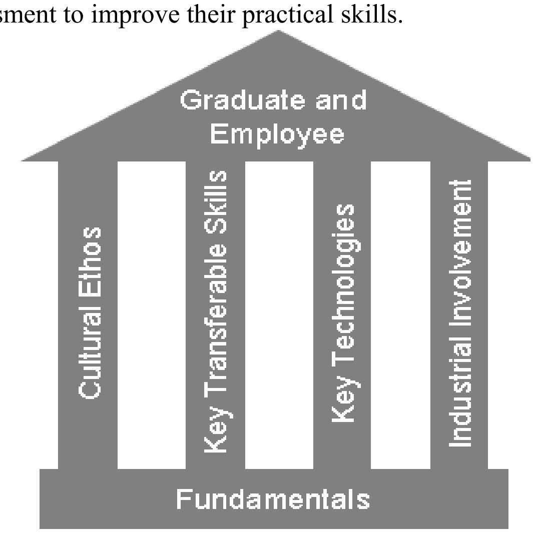


FIGURE 2
GUIDING PILLARS

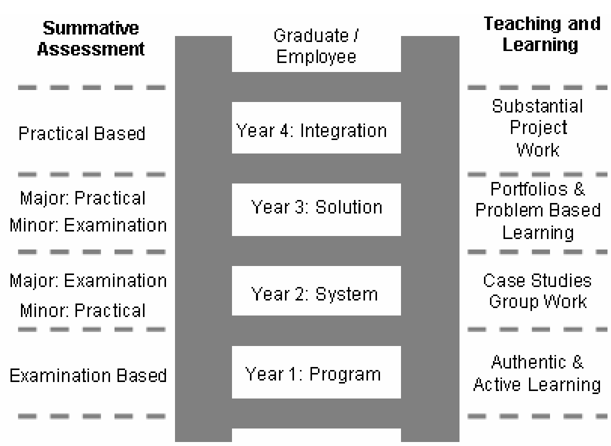


FIGURE 3
THE LADDER OF ACHIEVEMENT

### CURRICULUM IMPLEMENTATION

The real test for our curriculum was presented through the need to adapt it for delivery in China. Our first concern was the specific nature of the Chinese environment and education system. The following are the main issues we encountered:

- *Mathematics*: Most technical postgraduate programmes in China require applicants to have a high level of ability in Mathematics. We were required, therefore, to modify the learning outcomes for the curriculum to cater for this, which impacted mainly on the first two stages of the curriculum.
- *Industry*: There is seldom much interaction between universities and industry in China during curriculum development. While encouraging this interaction, we also needed to make clear what we considered the benefits of ongoing industrial involvement in the delivery of the curriculum would be.
- *Final Year*: The degree programmes in the university for which the curriculum was being developed typically reserve the final year for work placement. This, apparently, is expected by industry in China, who see the year as the first stage of graduate recruitment. Changing this to third year (as is common in Irish Universities) for our curriculum would result in graduates being disadvantaged when seeking post graduate employment. We incorporated this idea into our curriculum, replacing typical final year modules with research papers and seminars and pushing some of the important content back to third year modules. This impacted substantially on the content of a number of the stages, but importantly, the overriding high level learning outcomes for the stages were retained.
- *Civics*: All Chinese undergraduate students are required to take several civics-type modules. These were incorporated into our curriculum, with the learning outcomes updated accordingly.
- *English*: The Chinese students on the programme will be taught through English. Three modules were incorporated into the early stages of the programme to facilitate this instruction. The possibility arose for these modules to assist in the assessment of many of the transferable skills which are stated as programme learning outcomes e.g. *presentation*, *communication*, etc.
- *Group Work*: This type of activity is less common in Chinese universities than in European universities. It was felt that additional attention should be paid to preparing students for working in teams, so the learning outcomes of some of the early modules and stages were updated to reflect this increased emphasis. Learning, teaching and assessment methods to support group work were emphasised in the documentation.
- *Assessment Criteria*: Chinese universities use a pass mark of 60%, whereas 40% is typical in Irish universities. The curriculum core identifies the criteria that are used to establish the grading of students [2], so all that was required for this implementation was a mapping from the appropriate grades to the criteria for reaching the grade.

An additional factor which required adaptation of the curriculum was the class size, which is generally significantly greater in China than Ireland. Appropriate learning and teaching methods for large classes such as the use of VLEs

present new opportunities for the assessment of existing learning outcomes (e.g. written communication), leading to a further modification to the curriculum.

The number of contact hours expected per week and the number of weeks in the academic year are both much higher in China than Ireland. A balance needed to be struck between the need to provide students with the time necessary to learn independently and meet informally, and the need to fit in to the local culture, where high levels of instruction are expected.

## ALIGNMENT FOR ONE SUBJECT AREA

One of the most important skills with which a graduate of this degree programme should be equipped is the ability to design, implement and test software. We consider in this section some of those modules which are used to facilitate the student's learning in this area, and show how alignment applies to these modules.

At stage 1 all students must take *Programming* and *Problem Solving* modules. At stage 2 students take *Object Oriented Programming*, *Algorithms and Data Structures* and *Software Engineering* modules.

The learning outcomes for stage 1 include:

1. The fundamentals of procedural programming and the principles of good coding practice and software testing.
2. The purpose and use of basic algorithms and data structures.
3. Various approaches to, and techniques for, problem solving.

and stage 2 learning outcomes include:

1. Design, implement and test object-oriented systems using an object oriented programming language.
2. Choose and implement appropriate algorithms and data structures to solve well-defined problems using object-oriented methods.

Stage learning outcomes can be assessed in multiple modules and where this possibility arises, this should be documented by the programme designers. For example, *programming* should not be taught to students who do not understand the requirement of programmers to use their skills in solving defined problems. Equally, students learning *problem solving* should be able to express particular solutions in a programming language. For this reason, the second and third learning outcomes for stage 1 should be treated in both of these modules, with joint assessment and synchronization of delivery being important considerations.

Equally, the learning outcomes at stage 2 serve as a superset of those at stage 1. The modules that the student takes are designed to not simply build on the material already delivered, but to present the student with opportunities to reconsider the methods used earlier in a new context (say, design and implementation of object oriented systems). Developing the student's critical analysis skills and ability to evaluate algorithms, methods and technologies is of crucial importance, and informs the type of vertical alignment used in our curriculum development process.

## SUMMARY

This paper adds to the large body of knowledge on curriculum development, alignment and adaptation. It presents a view that the curriculum should be viewed as two parts, a core that is general and widely applicable, and an implementation that may require addition to and adaptation of the core. For adaptation to be effective, the curriculum must be aligned along three dimensions, horizontally, vertically and constructively. The three dimensions combine to form our model of *3D Alignment*. As well as guiding the curriculum design process, the 3D Alignment model defines a space into which all curricula and elements fit. Successful curricula should be firmly rooted at the centre of the diagram shown in Figure 1. By measuring the distance from the centre to the position of a curriculum, those involved in reviewing the effectiveness of the curriculum can calculate the degree to which the elements are aligned, and can then act accordingly in redesigning the curriculum. We have described its employment in the design and adaptation of a Software Engineering curriculum for a Chinese university.

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