International Journal of Engineering Education Vol. 30, No. 6(A), pp. 1425–1435, 2014
Printed in Great Britain

0949-149X/91 $3.00+0.00

Enhancement of Learning for Engineering Students through Constructivist Methods*

PATRICK J. FRAWLEY[1] and NIALL PRENDERGAST[2]
[1] Mechanical, Aeronautical and Biomedical Engineering, MSSI,University of Limerick, Ireland. E-mail: Patrick.Frawley@ul.ie
[2] Engineering Centre, Bombardier Aerospace, Belfast, Northern Ireland. E-mail: niall_prendergast@hotmail.com

In student feedback, many students expressed difficulty with the concepts being taught. There was a difficulty with quick, in-class retrieval of information. To facilitate transfer, understanding and retention of knowledge there needs to be prior knowledge in the long-term memory. In the case of complex engineering problems, the performance outputs are a function of many input variables. Airfoil design is a good example—the engineer needs to understand the dependence of performance parameters on the input conditions along with the physical phenomena. Visual representation is a powerful means of depicting cause and effect relationships. It can be reasoned by adding relational, interpretive visuals to a lesson, a higher level of learning will occur. In the proposed interactive program the student is given control of input variables and can see the influence these have on the primary aerodynamic concepts. It creates realistic configurations from complex theoretical calculations, facilitating the storage of information in the long-term memory. This when complemented with traditional teaching methods, allows the student to develop conceptual understanding. The programme was used in second year undergraduate engineering teaching and over a three-year period was monitored and improved. Students' performance was used to assess the effectiveness of the learning technique, as was student module feedback. The average class size for courses investigated was 26 students. The students performed better using this approach. It generated a motivation for further enquiry in the students and created an enthusiasm for student–student and student–lecturer interaction. This agrees with the constructivist theories and how social psychology affects learning.

Keywords: technology education; constructivist learning; GUI; airfoil design

1. Introduction

The overall goal of Science and Engineering education is to provide the student with the guidance and the tools to take on relevant information, understand scientific principles and apply the knowledge gained to real-life design and problem solving. Mechanical and Aeronautical Engineering modules are difficult for students. For example Aerodynamics requires understanding of the physics of fluid flow and the governing equations. In student feedback, many students expressed difficulty with the concepts being taught. In 2008, a revision of an Aerodynamics module offered at the University of Limerick was initiated. There was a difficulty with Transfer of Knowledge and with quick, in-class retrieval of information from long-term memory. This subject depends heavily upon a plethora of multidisciplinary concepts. An alternative to teacher dominated learning situations was supplied though software designed in-house. Extensive research was carried out into the psychology behind the learning process in order to assess enhancement of learning through the use of Graphical User Interfaces. The GUI design procedure was studied in great detail; the phases involved were then related to this project.

Understanding can be classified as a type of explicit learning. It is one of the most difficult types of explicit learning as it tends to push the limits of the working memory. It requires the ability to control one's thought process while reflecting on knowledge stored in the long-term memory; this is a mentally demanding cogitative activity. The difficulty in understanding and how it is often avoided has been investigated [1, 2]. This preference to problem solving or memorisation can lead to difficulty when trying to change intuitive theories. Without understanding the concepts, new information is added to the long-term memory without preconceived ideas being revised and updated [3, 4]. This is very relevant to students studying Aerodynamics as misunderstanding concepts may result in poor understanding.

An important distinction to make at this point is the difference between analytical and numerical solutions to problems. While this project has the goal of creating a learning tool for a mathematical equation it does not aim to solve the equation numerically. A numerical solution is one that has numerical value, i.e. enter a set of variables and an exact solution (a number) appears. An analytical solution is a demonstration of cause and effect, i.e. fluctuation in the value of specific variable leads to changes in the output. A very similar idea when comparing representational and solution problem solving is described by Sternberg and Ben-Zeev [5]. 'Representation occurs when a problem solver

* Accepted 9 July 2014.

seeks to understand the problem and a solution occurs when a problem solver actually carries out the actions needed to solve the problem.' This is an interesting finding that would lead one to believe that if, during the learning process, emphasis is put only on carrying out a procedure and adhering to a set of particular rules, the depth of understanding of a problem and the meaning of the solution is lost and therein lies the problem.

A study [6] examined the behaviour of students and the effectiveness of education of fluid mechanics and heat transfer through computer aided learning (CAL). The study explains how these areas of engineering provide formidable mathematical and conceptual obstacles, which are also quite time consuming to overcome. As a result, undergraduate courses usually did not delve much deeper than the basics or what he refers to as the foothills of the subjects. The problem presented here is how to ensure that the student achieves a high level of understanding if they are so restricted. A programme was developed using an algorithm to solve two-dimensional flow problems. From examining this study it can be seen that there are huge benefits from the advances made in technology in relation to learning and specifically engineering. In order to take full advantage of these advancements, it is of extreme importance for this technology to be used correctly to ensure the learning process is efficient and effective. By employing the constructivist learning method and using Graphicacy through technology such as a GUI, the students are encouraged to actively learn, as opposed to memorising, information and facts for repetition. Other works of a similar nature include [7–9].

2. Constructivist learning

Constructivism aims to provide an alternative to teacher dominated learning situations. It encourages discovery through guided and supervised experimentation, trial and error and examination. It is a middle ground between a complete teacher dominated learning atmosphere and unsupervised student discovery. Successful constructivist learning reduces student rote memorisation of material and facts and encourages the student to challenge their knowledge, theories held and progress through discovering the information themselves. The teacher and the student need to actively organise, elaborate on and interpret knowledge [10]. It is not sufficient to merely repeat and memorise the information. Also the student needs to learn new concepts as organised related information and not just as random lists of unrelated information. Dewey, and Montesorri and Kolb [11, 12] all advocated the value of experiential learning to conditionalise knowledge. It is vital for learning to employ exploration, thinking, reflection and interaction techniques [13, 14]. Based on Kolb's theory, the importance of experiental learning has been demonstrated [15].

This is important in relation to engineering. A student with a weak understanding of a topic or engineering concept could memorise the necessary information, formulae and processes in order to complete a problem or pass an exam. In this scenario the student has performed to a satisfactory level; however his/her level of knowledge and understanding of the topic could still be quite poor. Constructivist learning is to encourage the student to 'create' their own knowledge. For active experiences to occur it requires the students to use previous knowledge in order to discover, challenge and experiment with new ideas [16, 17]. During active learning a student will create new ideas themselves by putting their previous knowledge to use in a way that is novel and meaningful. Constructivist methods of learning are present in education today. However, they can sometimes be overlooked by the educators. Lecturers, teachers and course directors may be aware of the advantages of these learning methods but still the more common option of the typical lecture style tends to dominate educational institutions. University science courses include laboratory work and mandatory coursework, which aids in the student's understanding of the theory learned in class by applying the information to an example of real-life application. Laboratory exercises and coursework are beneficial to the student but still lack a constructivist approach.

The three phases of constructivist learning are engagement, elaboration and reflection. During these phases the student will engage with a task, elaborate on the task and reflect on his/her progress towards completion. These three stages of learning occur through the student's interaction with other students while under the guidance and supervision of the lecturer. The use of this system of teaching and learning ensures the student is kept active and stimulated through the interaction with peers and the challenge of the task. In order for a student to complete a task they are required to use the information available to them and the knowledge already possessed to create possible solutions and theories of their own. An added benefit of peer interaction includes students' discussions of new formed theories while learning from the group. The teacher's role of supervision is crucial as students can form incorrect theories that need correction to prevent the formation of incorrect conclusions leading to task failure. The constructivist approach allows students to develop new skills so that they are increasingly capable of solving a wide variety of meaningful problems and allows the students to become autonomous and self-motivated in their mathematical activity [18]. To enhance education through constructivist methods it is required to (a) encourage discovery through guided and supervised experimentation and examination; (b) actively organise, elaborate on and interpret knowledge; and (c) use previous knowledge to discover, challenge and experiment with new ideas.

2.1 Psychology of learning

In order to learn and understand it is vital to analyse how the student receives new information, how that information is actively processed and how that information is integrated with long-term memory. Embedding knowledge in the long-term memory is vital for retrieval and transferral of knowledge. Managing social interactions allows for the management of knowledge transfer in a structured way.

Marzano investigated acquiring and integrating knowledge and showed that knowledge needs to be transferred to long-term memory by integration with prior knowledge for it to be retained and understood [19]. During the learning process, students are trying to relate new information being supplied to previous knowledge. If this is not accomplished, new information is not transferred and is forgotten.

In the case of complex engineering problems, the performance outputs are a function of many input variables. The engineer needs to understand the dependence of performance parameters on the input conditions along with the physical phenomena. The proposed addition to the constructivist method is the use of visual representation as a means of aiding the preconditioning and acquisition of prior knowledge. Incorporating visual objects with verbal information can lead to better learning [20]. Virtual labs have been used to visualise experiments. In a study that combined a hands-on lab with a virtual lab it was found that students preferred the hands-on lab [21]. The Graphical User Interface being proposed here combines the results of 720 separate experiments and these are combined towards a guided learning experience. To do this in a laboratory setting within the time constraints would be impossible.

Cognitive change is produced by social interaction [8]. Peer interaction during the learning process can be very beneficial. The gap in knowledge between the teacher and the student can be significant. As a result it may be difficult to identify the source of confusion when studying a topic. Peer to peer and student–teacher interaction is vital in learning. These two types of interaction can be harnessed within constructivist learning.

2.2 Technology and learning

As technology advances, engineering and science industries are changing. These advances in technology that are extremely useful in industry can also aid in education. It is obvious in modern engineering and science that the use of computers, computer software packages and new technologically advanced equipment has caused procedures to change and made challenging objectives achievable. If this is the case then teaching and learning of engineering should follow. As well as changing how we learn it has also changed the role of engineers in the workplace:

> The role of aerodynamics in aerospace engineering, while still important, is no longer the dominant driver in aircraft design. Furthermore, industry, government, and academia—the likely employers of aerospace graduates—desire a workforce which is the more holistic and systems-thinking as opposed to the highly specialized, research-oriented engineer of past generations [5].

Technology is present in everyday engineering education. Examples are computer aided design packages, computational fluid dynamics, MATLAB and Microsoft office. These are used as tools to aid in the completion of engineering tasks rather than in conjunction with previously discussed constructivist learning. These packages solve engineering problems and aid in designs to achieve engineering objectives more efficiently. They do provide the student with an alternative from teacher dominated situations and prevent rote memorisation of material, while giving the student an example

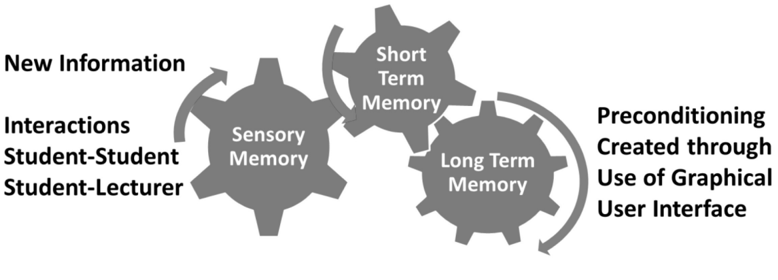


Fig. 1. Retention and understanding.

of the real-life application of engineering. However, they are designed with the primary goal of the solution to an engineering problem and not the teaching of engineering theories. As a result, students could learn how to use a Finite Element Analysis package and complete the analysis of a structure under given loading conditions. However, they would not gain any knowledge of the theories behind this, such as what they would learn in the Mechanics of Solids.

2.3 Graphical User Interface software review

When determining the overall effectiveness of a Graphical User Interface designs [22, 23], it was found 'while it is the user's job to focus on the tasks, the designer's job is to look beyond the task to identify the user's goal'. The process of conceptual design is described as follows:

> In the user interface design, the conceptual level involves analysing users' needs in terms of the activities that need to be accomplished using a system and the objects and the operations which a user has to employ to accomplish the tasks [24].

During the initial stages of this project, research was conducted into the various types of software available to design a Graphical User Interface. MATLAB by MathWorks was found to have desired advantages. This package provided superior options in relation to handling data and also was far superior and user friendly when plotting data to the other software. In recent years Microsoft Visual Studio has been changing science and engineering. Now many engineers use Visual Studio to write programmes or build controllers with Graphical User Interfaces. Visual Studio interfaces are found in many laboratories and excel at controlling, co-ordinating and acquiring data from instrumentation [25]. Visual Studio is an integrated development environment (IDE) software package available for free download from Microsoft. This package is used to design Graphical User Interfaces, web sites and online applications. Incorporated into the Visual Studio interface is a code editor and form designer. The code editor uses IntelliSense, which is a tool to aid in speeding up code writing in software development. Writing code can be quite confusing due to the volume of commands, variables and symbols to be remembered. IntelliSense works by accessing a database that has stored all commands and variables created by the designer. It works by detecting characters entered into the code and providing predictions in a pop-up menu for the user to choose from, similar to predictive text on a mobile phone. The user can accept one of these commands by pressing 'enter' and it saves them from typing the whole line of code. In this code editor the designer has the ability to edit properties of application such as images colours, backgrounds, visual effects and sounds but most importantly the working of the interface such as buttons, menus, checkboxes and other controls.

3. Data acquisition and visualisation

A Graphical User Interface was designed that enables a student to analyse and compare nine similar aerofoils and observe how their aerodynamic characteristics change when their geometry is changed. Students are encouraged to gain understanding through guided experimentation and through trial and error. In this way the student puts their previous knowledge to use in a way that is novel and meaningful. The project has developed and provided the students with software that lets the student test the effect of changes in variables on output. As part of the module, the students were supplied with software to examine the process in designing an airfoil for a particular application. Student groups were challenged to come up with the best solution for a practical problem e.g. wind-turbine blade. It proved to be a powerful tool in enabling the students to interpret the course material.

In the proposed interactive program the student is given control of input variables and can see the influence that these have in the primary aerodynamic concepts. It creates realistic configurations from complex abstract calculations, allowing the student to fully appreciate the value of their work. The varying of airfoil geometry such as camber, camber position, maximum thickness and position of maximum thickness was carried out to analyse the effects that this had on aerodynamic characteristics. Nine airfoils of different geometry were analysed and compared. The data obtained through this research was portrayed using graphical illustrations such as airfoil images and data plots with the aid of a designed Graphical User Interface. The data was then analysed and plotted with the aid of MATLAB, followed by coding into the user interface, which was designed through Microsoft Visual Studio 2010. This project alternatively used software to obtain simulated experimental data opposed to data obtained through conventional laboratory testing. To collect data from XFLR5, a NACA 4415 airfoil was loaded into the airfoil design interface in XFLR5. With this airfoil selected in the analysis section of XFLR5, testing conditions were defined, e.g. Reynolds numbers, angle of attack range and, following this, analysis was initiated. The nine airfoils were variants of the NACA 4415, each one having one particular characteristic changed to make a new airfoil. The characteristics changed were camber, position of

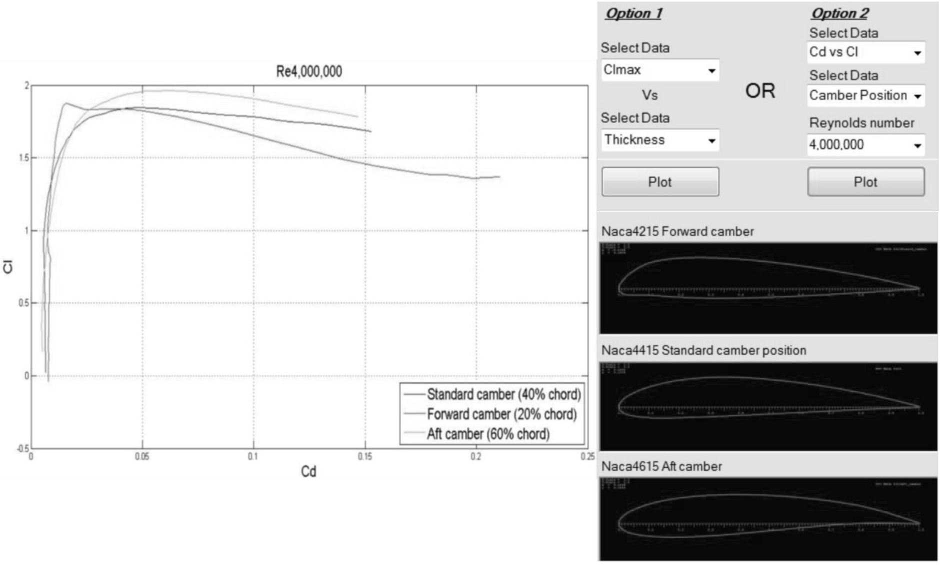
Table 1. Characteristics of nine analysed airfoils through XFLR5

Airfoil	Camber (% chord)	Position of max. camber (% chord)	Thickness (% chord)	Position of max. thickness (% chord)
Base airfoil NACA 4415	4	40	15	30
Position of max. camber moved aft NACA 4615	4	60	15	30
Position of max. camber moved forward NACA 4215	4	20	15	30
Increased camber NACA 6415	6	40	15	30
Decreased camber NACA 2415	2	40	15	30
Position of max. thickness moved aft NACA 4415/X	4	40	15	35
Position of max. thickness moved forward NACA 4415/Y	4	40	15	15
Increased max. thickness NACA 4420	4	40	20	30
Decreased max. thickness NACA 4410	4	40	10	30

maximum camber, thickness and position of maximum thickness. Each of these variables was increased and decreased from the initial 4415 settings and analysed. Table 1 outlines the characteristic of the nine analysed airfoils. The NACA four-digit wing sections define the airfoil as follows: the first number gives the maximum camber as a percentage of the chord; the second number gives the distance of maximum camber from the airfoil leading edge in tens of percent of the chord and the last two numbers gives the maximum thickness of the airfoil as a percentage of the chord. This table shows the design space of the geometry and this when combined with the two flow conditions, Reynolds number and angle of attack, indicates the 720 separate experiments required for a guided learning experience.

The results from the completed analysis are displayed as in Figs 2 and 3. Under option 2 (Fig. 2) the user can select a plot of either C_L vs. α, C_M (Pitching Moment Coefficient) vs. α or C_M vs. C_D for varying camber, camber position, thickness or thickness position for a specific Reynolds number. This shows Coefficient of Lift (C_L) vs. Coefficient of Drag (C_D) plot for changing camber position at a Reynolds number (*Re*) of 4 000 000. The student can visualise the changes in airfoil performance (C_L and C_D) with changes in geometry and angle of attack and so can comprehend changes to geometry and how that might affect performance.

As the data was displayed in graphical form and it was required in numerical form, the export polar function in XFLR5 was used. Using this function the numerical data was exported as .txt files. These



Select Data: Clmax
Select Data: Thickness

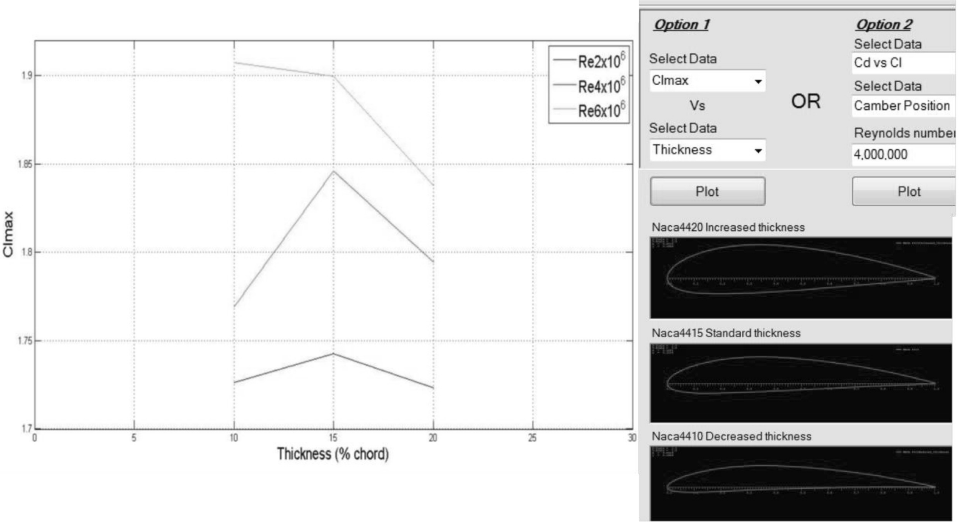
Select Data: Cd vs Cl
Select Data: Camber Position
Reynolds number: 4,000,000

Naca4215 Forward camber

Naca4415 Standard camber position

Naca4615 Aft camber

Fig. 2. Plot of C_L vs. C_D for changing camber position at Reynolds number 4 000 000.



Select Data
Clmax
Select Data
Thickness

Select Data
Cd vs Cl
Select Data
Camber Position
Reynolds numbe
4,000,000

Naca4420 Increased thickness
Naca4415 Standard thickness
Naca4410 Decreased thickness

Fig. 3. Maximum Lift Coefficient for varying airfoil thickness and Reynolds numbers.

files were then copied and pasted into Excel in order to assign the separate sets of data to cells. With the data now in this from, each column could be copied into MATLAB and saved as a single variable, allowing manipulation of single variables and generation of desired plots. This process was repeated until all the data was saved in the MATLAB workspace. This was a long, tedious, repetitive process but was necessary in order to achieve the required graphs. With all the numerical data saved in the workspace area it was possible to call upon whichever graph was desired.

By using the code, any of the desired graphs could be called upon by simply adjusting the code for the desired variables. This process was repeated until all graphs were plotted and saved as images in jpeg format. It was also necessary to obtain plots for C_{Lmax}, C_{Mmin} (Moment Coefficient) and E_{max} (maximum aerodynamic efficiency)—Option 1 (Fig. 3). This was done to give the user of the interface a graphical representation in one graph of how the lift, drag or moment characteristics of a given airfoil change as the camber, camber position, thickness or thickness position changed. To leave this out would mean that it would be difficult for the user to compare C_{Lmax} for two different camber positions. E_{max} is a ratio of C_L/C_D, which can be graphically approximated by drawing a line tangent to the C_L vs. C_D curve from the origin. Where the line touches the curve gives an E value. This is the optimum ratio of C_L/C_D for the airfoil to operate at the given Reynolds number. Similarly it was also required to obtain plots for C_{Lmax} (Fig. 3) and C_{Mmax}. To do this the maximum values for each corresponding to each airfoil at each varied camber, camber position, thickness and thickness position were defined as new variables in the MATLAB workspace. This allows the student to visualise how changes in flow conditions with geometrical changes affect performance.

The GUI provides the user with a graphical image to which to relate the information. The user has the option to view the changes that occur graphically and numerically.

4. Methodology

In the proposed interactive program the student was given control of input variables and could see the influence these have on the primary aerodynamic concepts. It creates realistic configurations from complex theoretical calculations, facilitating the storage of information in the long-term memory. This, when complemented with traditional teaching methods, allows the student to develop conceptual understanding. The overall teaching method is composed of a number of unit operations sequentially put together to enable the student to promote active learning and understanding. The process allows the student to 'construct' their own knowledge through experimentation and investigating 'cause and effect'. The lecturer acts to guide the student through elaborating on the reasons for 'cause and effect' and through reflective practices.

At the start of the semester students are introduced to the Graphical User Interface and XFLR5. The interface and the software were freely available on the internet. The students were split into groups and within each group a member was instructed to study the effect of two different variables on airfoil performance. This allowed each group member to be an expert on a particular issue. Knowledge was gained via experience in visualising effects through the Graphical User Interface. Students work autonomously in the learning process.

Within lectures, reference was made to the physical phenomena and the governing equations. This was linked to the effect of performance as seen through the Graphical User Interface. A peer observation study of the module was carried out in 2013 involving two peers from the department and a representative from the Centre of Teaching and Learning. This study investigated the outcomes, style and approach and student participation in the module. This contributed greatly to a confidence in the methods being used. Peer observation was found to good for confidence building [26, 27]. In answer to the question 'To what extent were students kept actively learning during the lectures?', one observer stated 'the lecturer makes lots of reference to coursework that the students are working on, which again makes the content real and perhaps relevant to them'. The dialogue between the student and the lecturer was created through the use of directed questions and initiation of group discussions. This created active participation of the student in the lecture and it was found that at the end of the lectures the students were more willing to discuss the theory and physics being taught.

After two weeks the student members within the group are asked to come together to analyse airfoils for different applications. This allows for good student–student interaction. This process is monitored by the lecturer and has been recognised as an important step. It has been found that student-to-student interaction leads to higher perceived competency development of students [28]. It has been recommended that collaborative learning strategies be used to promote reflection, conceptualisation, and active experimentation. The students were given a specific task to design an object within a design space and were informed that the marks for the coursework would be linked to the quality of the design.

The designs were investigated by the lecturer and in a formal feedback session the merits of each design were discussed and also how each design might be improved. During this process there is a discussion of the physics and the equations being used. This allows for reflection and so generates meaningful learning [29]. This also creates good student–lecturer interaction.

These techniques are complementary to traditional techniques and laboratory work is performed to allow the students to gain hands-on experience and to discover the limitations of theory and the assumptions made. It allows for the necessity to teach problem solving methodologies explicitly within engineering [30]. Studies have stressed the importance of experiments within education [31, 32]. Creating the laboratory component in this way addresses the proposition put forward that states 'the often poor learning outcome of the laboratory session is mainly due to weak activation of the prehension dimension of the learning cycle, before coming to the lab' [33]. The best airfoil design was constructed in a 3D printer and experimentally tested in the wind-tunnel by the students. In the lab a three component balance was used to measure lift, drag and pitching moment for different angles of attack and Reynolds' number. Comparison was made with theory and this further strengthened the understanding and retention of knowledge.

Engineers in general are visually orientated so this inductive approach has reinforced students' understanding of how an airfoil's performance can be altered by changing geometry and boundary conditions. Thus, a strong cognitive preference for the visual transmission of information is supported by this approach. After examining all the data collected for the nine airfoils generated from varying camber, camber position, thickness and thickness position from a NACA 4415, the following are some observations that can be made by the students. The GUI enabled the students to understand and apply the knowledge to airfoil design.

Airfoil Camber

- Increasing camber increases maximum lift coefficient.
- Increasing camber increases lift and consequently E_{max} also increases.
- Increasing camber increases negative (nose down) pitching moment.
- There is an increasing nose down pitching moment as camber position moves aft.

The students are asked to submit a report discussing the following:

1. the effect of boundary layers on the lift and pitching moment trends, at both low and high Re;
2. the variation of viscous drag as angle of attack and Re changes;
3. corrections required for a three-dimensional wing;
4. boundary layer separation, transition and reattachment points from Coefficient of Pressure plots.

Based on this improved understanding, students were then assigned a problem to solve, e.g., the goal is to find the best NACA airfoil to act as a wind-turbine blade. The problem is constrained through values defined for camber, location of camber and thickness. The Mach number (*M*) and the Reynolds number (*Re*) are defined by the

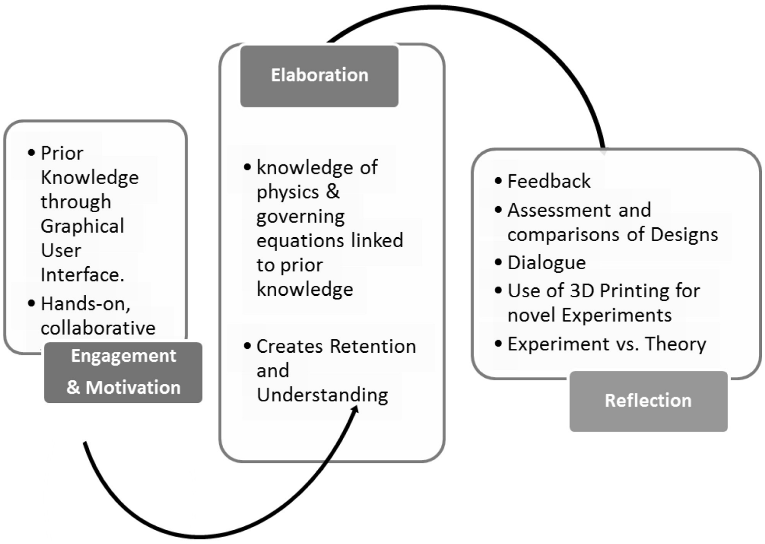


Fig. 4. Enhancement of learning through constructivist methods.

students based on literature reviews relating to operating conditions. The students were shown how to accomplish this task in a methodical way by using their understanding of geometry and conditions on the aerodynamic performance. The results of the study demonstrated that students have a desire to successfully complete the task when using the software. The new approach and assessment method has proven very effective and has been commended by external academics. In a recent (2012) report, Professor C. J. Atkin stated:

> I applaud the successful introduction of computational tools to allow students practical experience of modern analysis and design software to explore the complex aerodynamics of variable wing shapes. The students' work I have seen has been of a high standard and the students have clearly found the course extremely stimulating and an enormous improvement on the previous teaching.

The students focused their efforts on the process needed to be undertaken to solve a problem though the software rather than the theory being memorised and complex calculations carried out.

This practice resulted in an improvement in the teaching environment as encoding information being taught in this way enabled the student to retrieve the required information during the class in an efficient way. This helped the students to internalise the topic and makes it easier for the student to visualise the relationships between topics, apply the knowledge gained and understand the theory, Fig. 4. Importantly, this inductive approach also enhanced lecturer-awareness during the class. Feedback was given to the class on the collaborative class based design undertaken in a formal lecture. This created competition within the class but also a motivation for further study to discover the physics behind the problem and so generate new designs. The effectiveness of this teaching approach was evaluated by using two methods: comparing student performance and Formative Student Evaluation of Teaching carried out by the Centre of Teaching and Learning at the University of Limerick.

4.1 Student performance

The students' performance was used to assess the effectiveness of the learning technique, Table 2. The exams in all cases accounted for 70% of the module score and the questions were designed to evaluate the learning outcomes and were linked to understanding. The coursework with the laboratory accounted for 30%. QCA is a quantitative measure of a student's performance with a QCA of 3.4–4.0, equating to a First Class degree; 3–3.39 to a 2.1

Table 2. Performance of Aeronautical Engineering students (2008 and 2012)

	2008 QCA	**2012 QCA**	**ΔQCA**
Aerodynamics	2.71	2.67	–0.04
Aircraft vibrations	2.48	2.16	–0.32
Class average for semester	2.77	2.49	–0.28
Class average end of year	2.87	2.61	–0.26

degree; 2.6–2.9 to a 2.2 degree; and 2–2.59 to a 3rd class degree.

From semester average QCA and end of year QCA for the year it was found that the class of 2008 was particularly strong: on degree completion, 50% of the class obtained First Class degrees, the average from 1994–2010 was 20%. The performance of the 2012 class was weaker (ΔQCA = –0.26). On reviewing the high school level education graduating results it was found that the there was a significant reduction in the number of students with a B3 or greater in mathematics from 2008 to 2012 (14 to 8).

Comparing Aerodynamics results pre and post the constructivist method employed, it was found that although the class from 2012 appears mathematically weaker, the performance in Aerodynamics is at the same level as in 2008. The average QCA for the Aerodynamics modules from 2005 to 2012 was 2.51. Both cohorts scored far higher than the average.

The same lecturer taught Aircraft Vibrations and Aerodynamics. In Aerodynamics, the average grade achieved was between a B3 and a C1 for both cohorts (ΔQCA = –0.04), while in Aircraft Vibrations it dropped from a C1 to a C3(ΔQCA = –0.32). The average QCA for the Aircraft Vibration modules from 2005 to 2012 was 2.35. The class of 2008 (2.48) scored above this average and the class of 2012 (2.16) scored below this mark. The only variable to be changed was the introduction of the Graphical User Interface and the coursework. The coursework percentage of the module was 15%, as in previous years. All other aspects of the courses remained the same.

These figure show that there is a marked improvement in performance using constructivist methods. In the Autumn Semester 2013, the students scored a QCA of 3.0. The group size in this situation was 40. This is an excellent result and through the examination process demonstrates that the constructivist method using visualisation techniques produced engineers with a good understanding of the concepts.

4.2 *Student Evaluation of teaching*

The Formative Student Evaluation is a structured approach to getting feedback from students on the quality of module content and delivery. It provides a valuable in-depth critical review of lecturing styles. This process is voluntary and confidential, and is designed to provide useful information to individual lectures on their students' experiences of the modules they teach. The formative feedback aims to allow the lecturer see the teaching and learning environment through the eyes of the student. It is important as 'we frequently misread how others perceive our actions' [34]. In addition to quantitative ratings, the evaluation also includes qualitative comments from individual students. Reflective practice is an important component of this type of feedback [35]. It helps to identify areas for improvement. It was through this process that it was found that many students expressed difficulty with the concepts being taught. The techniques developed here were in response to this problem.

The survey was conducted online with 10 lecturer items, 8 module items, 7 student items and carried out using a 5 point Livert Scale. The survey is carried out autonomously and anomalously by the University and the lecturer is not privy to individual information. The average class size for courses investigated was 26 students. The response rate for both cohorts was > 40%. Although the sample sizes are small, the trends are valuable.

This has been used to compare feedback of students taught with the approach being proposed here (class 2012) with a group from another academic year (2004) that had not the constructivist approach. Both courses were taught by the same lecturer. In the earlier evaluation (2004) the students noted that the information was 'hard to digest' and 'understanding notes was difficult due to all the equations'. The overall effectiveness of the module in 2012 as scored by the students was 4.4/5 (an increase of 13% on the 2004 results). All items relating to lecturing showed a positive shift showing an improvement, Fig. 5.

It was interesting to note that the most positive influence was on the motivation of further enquiry (5/5) and interaction with the students and the lecturer (4.6/5). These values are a reflection of the student–student and student–lecturer interactions that have been created through this approach.

This inductive teaching approach, introducing a real-life problem and showing how it can be solved, brings real enthusiasm to the class (4.8/5) and leads the student on to the theoretical aspects of problem solving. Conceptual understanding of the subject has been enhanced by these constructivist methods and there is now a desire to introduce these methods to other courses.

As part of the Aerodynamics module, feedback was obtained for the last three years on the effect that the new methods have made on the understanding of the course from the class and the following are the comments.

> This project really advanced our knowledge of airfoil design—much more so than just reading about it in books. This combined with our lab using the wind tunnel really turned the screw in terms of understanding. (2011)
>
> It would be recommended to use this type of software with any future course study as we have found it to be a great source of learning and understanding for complex concepts. (2010)

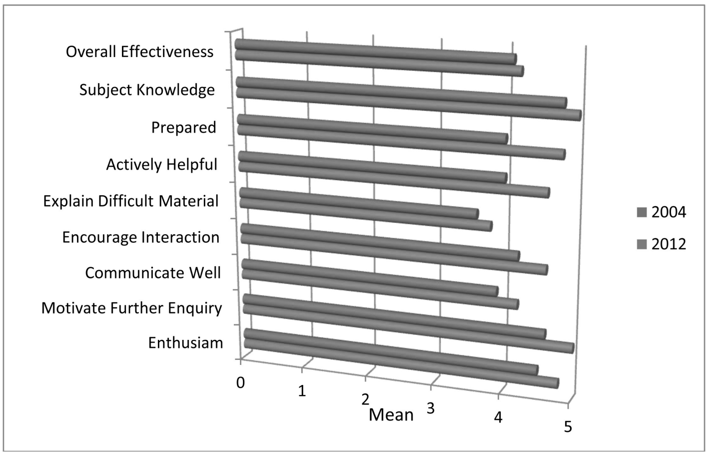


Fig. 5. Student Evaluation of Teaching from pre and post implementation of constructivist methods.

5. Conclusion

By employing the constructivist learning method through technology such as a Graphical User Interface, the students are encouraged to actively learn as opposed to memorisation of information and facts for repetition. An alternative to teacher dominated learning situations is supplied though the software designed. Three components were found vital to this approach.

First, engagement and motivation was created through the use of the GUI. Students were encouraged to gain understanding through guided experimentation and through trial and error. Secondly, elaboration in lectures was provided by relating theoretical and practical aspects to the information the students would have gained from the GUI. In this way the student puts the previous knowledge to use in a way that is novel and meaningful. This inductive teaching approach, introducing a real-life problem and showing how it can be solved, brings real enthusiasm to the class and leads the student on to the theoretical aspects of problem solving. The students were challenged to find the best solution to a practical problem. It generated a motivation for further enquiry in the students and created an enthusiasm for student–student and student–lecturer interaction. The students in this way developed communication and project management skills. Thirdly, the formation of reflective practice is vital to the process. The student takes ownership of the design and process. In this way the student has a vested interest. Feedback is essential. If the design is not a good as the students' peers, he or she is guided through the process of how it could be improved on and in this way they gain real understanding.

The creation of a program that serves to help students better conceptualise airfoil design is a favourable addition to the learning resources available. It was found that the students brought these techniques and tools into third and fourth year where they used it in a design, build fly project, Computational Fluid Dynamics and in final year projects. This was done by the students autonomously. The investment required to replicate this approach for their areas is worthwhile as many of the tools employed are available in third level education—engineering software for analysis, MATLAB and Excel.

The proposed techniques enhanced the student experience and moved from a conventional lecture type to a more active learning approach. By using these techniques, the authors' knowledge of teaching and of the subject matter have been increased. The students, through these techniques, have been motivated towards further study and this is important because their goals and needs will be different from the past. It is possible using the tools and techniques now available to us today to make good engineers and scientists from students who may appear weaker mathematically. In the future there is a need to investigate student–student interaction as it is an important component in this method. How can we make students be more productive in teams? There is also a need to incorporate these techniques in other modules delivered and prove its efficacy.

Acknowledgements—The author would like to acknowledge the participation from Professor Chris Atkin, City University London and Dr Bob Strunz at the University of Limerick who were involved in this effort including the Centre of Teaching and Learning office.

References

1. R. J. Stevenson and J. A. Palmer, *Learning: Principles, Processes and Practices*, 1st edn, Cassell Education Limited, London, 1994.

2. D. P. Newton, *Teaching for Understanding: What It Is and How to Do It?,* Routledge, Oxford, UK, 2011.
3. R. Clark and C. Lyons, *Graphics for Learning: Proven Guidelines for Planning, Designing and Evaluating Visuals in Training Materials*, Pfeiffer, San Francisco, 2011.
4. M. Çalik, A. Kolomuç and Z. Karagölge, The effect of conceptual change pedagogy on students' conceptions of rate of reaction, *Journal of Science Education and Technology*, **19**(5), 2010, pp. 422–433.
5. R. J. Sternberg and T. Ben-Zeev, *The Nature of Mathematical Thinking*, 1st edn, Lawerence Erlbaum Associates Publishers, Mahwah, NJ, 1996.
6. D. Tawney, *Learning Through Computers*, The Macmillan Press Limited, London, 1979.
7. D. Darmofal, E. Murman and M. Love, Re-engineering aerodynamics education, *AIAA Aerospace Sciences Meeting*, Reno, NV, January 2001, AIAA Paper No. 2001-0870.
8. J. Dudrik and P. Bauer, New methods in teaching power electronics converters and devices, *International Journal Engineering Education*, **24**(5), 2008, pp. 1040–1048.
9. C. Clayburn, S. Ervay and N. Albrecht, Attitudes of American teachers preparing to become administrators toward teaching creative strategies, *Creative Education,* **3**(01), 2012, p. 24.
10. S. M. Glynn, R. H. Yeaney and B. K. Britton, *The Psychology of Learning Science*, Lawrence Erlbaum Associates, Hillsdale, NJ, 1991.
11. M. Montessori, *Education for a New World*, Kalakshetra Publications, Madras, India, 1946.
12. D. Kolb, *Experiential Learning: Experience as the Source of Learning and Development*, Prentice Hall, Englewood Cliffs, NJ, 1984.
13. T. Litzinger, L. R. Lattuca, R. Hadgraft and W. Newstetter, Engineering education and the development of expertise. *Journal of Engineering Education*, **100**(1), 2011, pp. 123–150.
14. L. E. Carlson and J. F. Sullivan, Hands-on engineering: learning by doing in the integrated teaching and learning program, *International Journal of Engineering Education*, **15**(1), 1999, pp. 20–31.
15. S. Moore and N. Kuol, Students evaluating teachers: exploring the importance of faculty reaction to feedback on teaching, *Teaching in Higher Education*, **10**(1), 2005, pp. 57–73.
16. K. J. Jones, P. J. Vermette and J. Paul, The constructivist mathematics classroom, *Mathematics Teaching*, **219**, 2011.
17. R. M. Cummings and D. W. Hall, Aircraft design for second-year undergraduate students, *International Journal of Engineering Education,* **21**(1), 2005.
18. D. H. Clements and M. T. Battista, Constructivist learning and teaching, *Arithmetic Teacher*, **38**(1), 1990, pp. 34–35.
19. R. J. Marzano, A theory-based meta-analysis of research on instruction, http://www.mcrel.org/products/learning/meta.pdf, accessed 12 December 2013.
20. R. E. Slavin, *Educational Psychology*, Prentice Hall, Upper Saddle River, NJ, 2005.
21. S. A. Engum, P. Jeffries and L. Fisher, Intravenous catheter training system: computer-based education versus traditional learning methods*, The American Journal of Surgery*, **186**(1), 2003, pp. 67–74.
22. A. Cooper, *About Face: The Essentials of User Interface Design*, IDG Books Worldwide Inc, Foster City, CA, 1995.
23. F. E. Ritter, G. D. Baxter and E. F. Churchill, *User-Centred Systems Design: A Brief History in Foundations for Designing User-Centered Systems*, Springer, London, 2014, pp. 33–54.
24. D. Benyon, T. Green and D. Bental, *Conceptual Modelling for User Interface Development*, Springer-Verlag, London, 1999.
25. M. F. Russo and M. M. Echols, *Automating Science and Engineering Laboratories with Visual Basic*, John Wiley and Sons, Canada, 1999.
26. P. Palmer, *The Courage to Teach*, Jossey-Bass, San Francisco, 1998.
27. K. Pressick-Kilborn and K. te Riele, Learning from reciprocal peer observation: a collaborative self-study, *Studying Teacher Education,* **4**(1), 2008, pp. 61–75.
28. A. Konak, T. K. Clark and M. Nasereddin, Using Kolb's Experiential Learning Cycle to improve student learning in virtual computer laboratories, *Computers and Education,* 72, 2014, pp. 11–22.
29. A. Hofstein and V. N. Lunetta., The laboratory in science education: foundations for the twenty-first century, *Science Education*, **88**(1), 2004, pp. 28–54.
30. I. Belski, J. Baglin and J. Harlim, Teaching TRIZ at university: a longitudinal study, *International Journal of Engineering Education*, **29**(2), 2013, pp. 346–354.
31. J. Hashemi, K. A. Austin, E. E. Anderson, N. Chandrasekhar and A. Majkowski, Elements of a realistic virtual laboratory experience in materials science: development and evaluation, *International Journal of Engineering Education*, **21**(3), 2005, pp. 534–545.
32. M. Ronen and M. Eliahu, Simulation—a bridge between theory and reality: the case of electric circuits. *Journal of Computer Assisted Learning*, **16**(1), 2000, pp. 14–26.
33. M. Abdulwahed and Z.K. Nagy, Applying Kolb's experiential learning cycle for laboratory education, *Journal of Engineering Education*, **98**(3), 2009, pp. 283–294.
34. S. Brookfield, *Becoming a Critically Reflective Teacher*, 1st edn, Jossey-Bass, San Francisco, 1995.
35. L. Harvey, Student feedback, *Quality in Higher Education*, **9**(1), 2003, pp. 3–20.

Patrick Frawley is a lecturer in Aerodynamics at the University of Limerick. He is interested in knowledge transfer and is currently engaged in managing the process-modelling aspect of the Synthesis and Solid State Pharmaceutical Centre, Ireland.

Niall Prendergast is a Stress Engineer currently working on the Global 7000/8000 project at Bombardier Aerospace, Belfast. His interests involve finite element modelling.