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Design of a Novel Diagnostic Tool for Student Performance in Engineering Degree Courses*

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This novel diagnostic tool is based on students' performance at second level and the subjects they studied, with their interests and resulting personality types from Holland's Interest Inventory.The intent is to provide an accurate predictor of student performance and in doing so also offer a detailed insight into the influences on student learning outcomes and retention.A greater understanding of the factors influencing student performance can lead to better-informed teaching and learning strategies, the appropriate application of additional support and, as a result, enhanced student learning outcomes and retention.The Self-Directed Search (SDS) interest inventory used in this research is widely regarded as the most contemporary and extensive test available.

Keywords: Diagnostic tool, interests, inventory, second level (high school) results, strategies

CONTEXT

THE IRISH EDUCATION SYSTEM has mainly three levels which cover fifteen years or more of a person's life:

1) primary education which lasts for eight years;
2) second level (high school) which lasts for five or six year and is divided into a three year junior secondary cycle, followed by a two- to three-year senior secondary cycle;
3) third level or higher level education in Ireland is offered by universities and institutes of specialised higher education.

Upon completion of secondary school (high school), students are examined through a state examination known as the Leaving Certificate. The average age for students sitting the Leaving Certificate exam is 18. Students are then awarded points based on their results in these exams. The maximum points available to students in the Leaving Certificate is 600 and an award of 400 points or above is considered very good. The number of points students achieve in the Leaving Certificate determines the course they are accepted for at university. Students studying at university are referred to as undergraduate students.

VARIABLE AND FIXED CHARACTERISTICS

On entering university, students present certain characteristics which are variable and others which are invariant to faculty members. Many invariant characteristics can continue to influence teaching strategies and student learning outcomes at third level. These are referred to as functional invariants. We have investigated the impact of two dominant functional invariants: students' interests and second level results, on third level performance. By better understanding these influences it is hypothesised that it will lead to enhanced student learning outcomes and retention. This will require informed change within engineering education, made necessary by recent trends in engineering. Over the second half of the 20th century there was a noticeable shift away from the teaching of 'applied engineering practice' at third level, toward an 'engineering science'-based education [1].As a result, industry began to find that students graduating from current engineering courses, while technically adept, lacked many of the skills and qualities required in real-world engineering situations [1, 2]. Recent trends have also seen significant drops in enrolment numbers and retention rates.

Recent trends

Declining engineering enrolments pose a potentially serious problem for the Irish economy. It is expected that Ireland will need seven per cent more engineering graduates each year until 2020 [3], and this view is also reflected by industry. McMasters from The Boeing Company anticipates that 'we will need as many engineers in the future as we can hope to create' [4]. It should be noted, however, that this prediction is made on the assumption that there will be a healthy and continuing growth in our national and global economy, which is hard to accurately predict. Nevertheless Siemens Ireland have also stressed the need for more engineering graduates from Irish Universities: 'A continuation

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of the dramatic shortage in engineering graduates will negatively impact on economic investment in Ireland' [5]. Between 2000 and 2006, level 8 engineering course acceptance in Ireland dropped by eight per cent [6]. This is a worrying trend given that there has been a marked increase in student numbers during the same period in most other level 8 courses, despite fewer students sitting the Leaving Certificate exam. This is not just a national phenomenon. Similar trends have been witnessed internationally and to a greater extent in the United States [7–9]. Also, 65 per cent of enrolled engineering students at The Fulton School of Engineering leave before graduating [10]. Many engineering colleges and universities have undertaken major recruitment efforts to address this issue. Such efforts may have limited potential for success given that student choice is heavily influenced by so many different variables. Third level choice is influenced both by student characteristics; such as previous academic performance and interests, and external influences:

- the influence of significant persons;
- the characteristics of the potential institution (including proximity);
- how that institution is perceived by the public [11].

Given the numerous variables influencing enrolment numbers, engineering courses seeking to improve their graduation rates are starting to see improvement of retention and current student learning outcomes as the most effective means to do so. For example, recent research at Dublin Institute of Technology, one of the largest engineering educators in the state, has begun to look at students' reasons for choosing an engineering course in DIT in an attempt to improve retention rates [8].

Given the strong academic records of the majority of students who enter level 8 engineering courses in Ireland (on average engineering students obtained 474 Leaving Certificate points on entry into a University of Limerick course), rates of attrition are surprising. Drop-out rates in engineering courses on average are much higher than the mean for other third level courses at 19.6 per cent. Therefore, approximately one in five engineering students who embark on a degree course in Ireland will fail to qualify from that course [12].

A common misconception is that most of the students who leave lack the academic ability to survive in an engineering discipline. However, given the high points requirement and previous academic record for the majority of engineering students in the country it is hard to believe that their third level performance is based entirely on academic ability. In fact, little difference has been identified between those who drop out and those who complete an engineering course [7, 13]. The true explanation appears to involve a complex set of factors including student attitudes towards the engineering course, students' previous education, learning styles, self-confidence and student interests [9, 14].

Academic ability is a contributing factor to student performance and retention; for example, previous research at the University of Limerick across a wide variety of courses not only stresses maths as an indicator of third level progress but also as a huge influence on drop out rates at college [14, 15]. However, academic ability may not be the most influential factor. At Hellenic Open University, students who failed to complete the course and those who did not receive an 'honours' degree upon completion, were interviewed. Most of them (66.9%) felt that while there was 'good organisation of studies by the Hellenic Open University, for various reasons (not related to the studies or the tutors) they did not perform well' [9]. Arguably students' emotions and motivations are not being taken into account in many cases and these have proved to affect attendance which in turn affects student performance [16, 17].

It is clear then that third level student performance is influenced by a complex and dynamic set of both internal and external variables. However, certain variables have a greater influence than others. Through improved understanding of the influences on student learning, better-informed teaching and learning strategies can be implemented. Better-informed tuition can lead to enhance student learning outcomes and lower attrition rates [18].

Influences on student learning outcomes and retention

Haag et al. at The Fulton School of Engineering surveyed students who left engineering courses before graduating to assess what factors had the greatest bearing on their decision to leave [10]. As a result they have identified four main categories that have the greatest bearing on student retention and also student learning outcomes:

1) Academic and Career Advising;
2) Engineering Course Structure and Curriculum;
3) Faculty;
4) High School Preparation (second level preparation).

Self-Directed Search (SDS), used for research conducted in the University of Limerick to assess the impact of students' interests and second level preparation on third level performance, is a more extensive version of the interest inventories used by the majority of career advisors at second level. When compared to students' third level results, this provides an accurate measurement of the impact of 'Academic and Career Advising' on engineering student performance. Performance in each subject at second level and overall results were also compared to students' third level performance. Collectively this provides an accurate measure of how presage influences (factors before

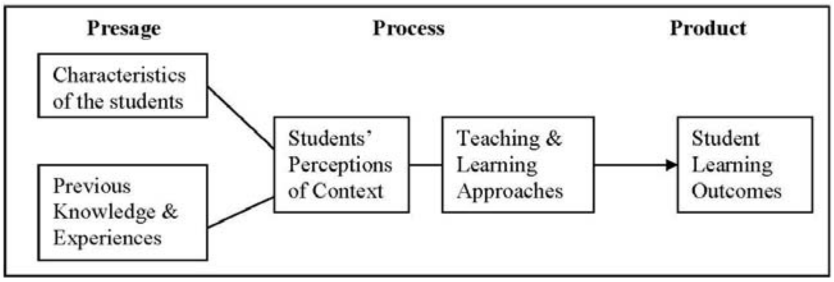

Fig. 1. Diagram of the student learning process.

Fig. 2. The Holland Hexagon.

university) impact upon undergraduate engineering performance.

EXPERIMENTAL DESIGN

The theoretical framework for this research is based on a model of classroom learning known as the Presage-Process-Product (3Ps) model [19].This methodology developed from Biggs' 3P's model, serves two functions. It is in itself a description of the student learning process but also simultaneously distinguishes several building blocks in identifying the influences on student learning outcomes. (See Figure 1, adapted from Prosser and Trigwell, [20])

This research concentrated primarily on the Presage influences on student learning outcomes which, in turn, impact on students' 'perceptions of context', (as seen in the above figure)—arguably one of the most influential factors in student attrition rates [14]. These, combined with teaching and learning approaches, have the greatest influence on student learning outcomes.

METHODOLOGY

Student interests and previous knowledge were compared with third level academic performance. Previous knowledge was identified through the Leaving Certificate results and the subject studied. Student interests were measured using John Holland's extensive interest inventory, the Self-Directed Search (SDS).The SDS assesses 228 items under four sections; it was developed to measure Holland's six types [21]. These refer to the six different personality types defined by Holland. These are illustrated by the Holland hexagon (see Figure 2. below)

- Realistic—practical, physical, hands-on, tool-orientated
- Investigative— analytical, intellectual, scientific, explorative
- Artistic—creative, original, independent, chaotic
- Social— cooperative, supporting, helping, healing/nurturing
- Enterprising—competitive environments, leadership, persuading
- Conventional—detail-orientated, organising, clerical

Holland has previously identified the personality types of engineers who excel in their discipline and has shown that successful engineers score highly in the realistic and investigative domains [22]. However, it is important to note that these are not isolated domains (with students only scoring in one or two of them) but a spectrum of interests. Students will show varying degrees of interest in all six types and it is where they score highest that Holland uses for his resulting codes, determining the best occupation for a particular individual [22].

PROFILE OF PARTICIPANT GROUPS

Students from the Mechanical and Aeronautical Engineering department at the University of Limerick were invited to participate in this study. They included students from three different courses; mechanical engineering, aeronautical engineering and biomedical engineering. Participating students were stratified under their current year of study in their respective four year degree courses. Table 1 shows the percentage participation rates from each year.

Table 2 shows the homogeneity of participating student year groups. The standard deviation for

Table 1. Percentage participation per year

Year	Total Cohort	Total Participants	% Total
1st Year	85	49	58%
2nd Year	66	29	44%
3rd Year	91	37	41%
4th Year	75	28	37%
Total Numbers	**317**	**143**	**45%**

the students' age remains constantly low throughout all four years of study, showing on average a linear increase in age (as expected). In total the sample cohort consisted of 17.48 per cent female participants which is consistent with female uptake of third level engineering courses in Ireland at present. For example, in 2006, 21.3 per cent of CAO students who accepted engineering courses were female [23].

STUDENT INTERESTS

On average, the students' results from the SDS interest inventory were directly in line with Holland's predicted results for successful engineers [22], as shown in Figure 3.

As can be seen in the above graph, students scored highest in the realistic and investigative domains as would be expected for those in an engineering discipline. People with a realistic and investigative personality like to think creatively and solve problem by 'doing', i.e. they like working on projects [22]. This has previously been highlighted by Holland as a common trait in all successful engineers.

COMPARING INTERESTS AND THIRD LEVEL RESULTS

Students' interests were then compared to third level academic performance known as their cumulative QCA or Quality Credit Average at the University of Limerick. For this purpose, first year students were disregarded for the same reasons that UL awards students a degree based only on the results they receive from second year onwards. The rationale for this is that it gives students a chance to familiarise themselves with the University, and acclimatise themselves to a different style of teaching and learning than they became familiar with in second level schools [24]. There are also the social and emotional pressures associated with the first year of undertaking a third level course. For these reasons and because first years would only have done one set of exams to date, their results have not been included. To further validate the omission of first year results, a comparison between year one, semester one results and the cumulative QCA was carried out. The resulting R square value was much lower than expected, at 0.167. Results showed a large variance between student first year results and their cumulative QCA compared to subsequent years, when, on average, results remained consistent. The results from each subsequent year provided a better predictor of student performance.

The following statistical analysis was performed to test the hypothesis that students' interests have an impact on student academic performance.

Multicollinearity: testing the hypothesis

The remaining students' interests were compared with their QCA using a correlation and

Table 2. Homogeneity of participating student year groups

Year	No.of Participants	Average Age	STDEV	Female	Male
1st Year	49	18.79	1.32	5	44
2nd Year	29	19.86	1.30	9	20
3rd Year	37	20.68	1.89	5	32
4th Year	28	21.44	0.96	6	22

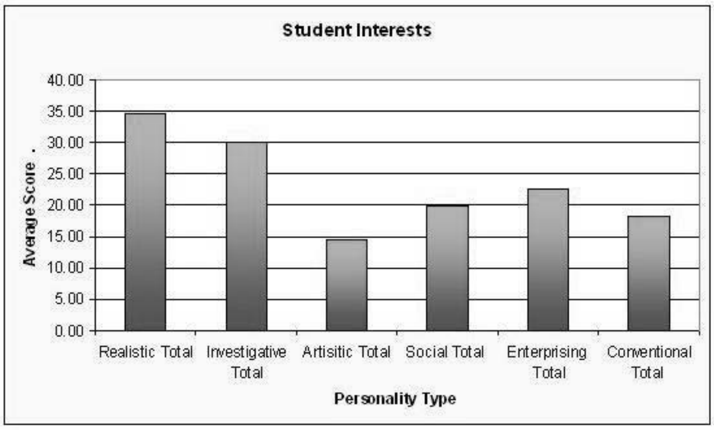

Fig. 3. Average SDS score for engineering students.

Table 3. Correlations between student interests and QCA

		Student QCA
Pearson Correlation	Realistic Total	0.293
	Investigative Total	0.401
	Artistic Total	–0.098
	Social Total	0.052
	Enterprising Total	–0.018
	Conventional Total	–0.082
	Realistic & Investigative	0.433

Table 4. Unique contribution of student interests

		Student QCA
Sig. (1-tailed)	Realistic Total	0.003
	Investigative Total	<0.001
	Artistic Total	0.181
	Social Total	0.315
	Enterprising Total	0.432
	Conventional Total	0.223
	Realistic & Investigative	<0.001

regression analysis to assess which (if any) of the six variables had the greatest influence on engineering students' third level results. As expected, after running a stepwise linear regression analysis of the results, taking students' QCA as the dependent variable and the six types (student interests) as the independent variables, the Realistic and Investigative domains were shown to have the highest positive correlation with student QCA. Consequently, these results were combined to form a new variable as suggested by Holland's Codes, and have been adapted for this research [21, 22]. The combined variable showed a higher correlation than the individual variables, as can be seen in Table 3.

As shown in Table 3, the independent variable having the strongest positive correlation with student QCA is the Investigative domain at 0.401. When this was combined with student results in the Realistic domain the positive correlation increased to 0.433.

Evaluating the model

In order to evaluate the above model the R Square value was calculated. This conveys how much of the variance in the dependent variable (Student QCA) is explained by the independent variables (Student Interests). In this case the value is 0.231, or 23 per cent. This means that a student's interests explain 23 per cent of the variance in student academic performance. When we considers all the variables that influence academic performance this value is substantial. More importantly, when the statistical significance of these results was calculated the Sig. value was 0.0001, which means $p<0.0005$.

Evaluating each of the independent variables

The realistic and investigative domains were the only two variables to show a statistically unique contribution (less than 0.05) to student QCA as shown in Table 4.

SECOND LEVEL RESULTS COMPARED WITH QCA

Twenty-four subjects were studied by the cohort at the second level. Of the 135 students who completed the study, only 117 had Leaving Certificate results on record. This is because 18 of them had entered the course as mature students or who had received equivalent second level accreditation from outside the country.

Upon analysis, where subjects studied at second level were compared with cumulative QCAs, only Mathematics, English, French, Irish and Physics produced statistically significant results. This was because of low student numbers in the remaining subjects at second level. For many of the subjects, fewer than ten studied them at second level and for some, Spanish for example, only one student studied them.

The following statistical analysis was performed to test the hypothesis that the subjects students studied at second level have an impact on third level academic performance.

Multicollinearity: testing the hypothesis

As expected from previous literature in the area [9, 14] Mathematics proved to have the highest positive correlation with student QCA. What did stand out, however, was that Physics was a very close second, as can be seen in Table 5.

Although not statistically significant (only 29 students studied the subject at second level) a substantial positive correlation of 0.489 was observed between Technical Graphics and student QCA. Importantly, no negative correlations were observed, suggesting that while certain subjects have a greater impact than others on student QCA, each has a positive effect.

Table 5. Correlation between subjects chosen at High School and QCA

		Student QCA
Pearson Correlation	Mathematics	0.490
	English	0.198
	French	0.314
	Irish	0.284
	Physics	0.426

Table 6. Unique contribution of subject choice

		Student QCA
Sig.	Mathematics	0.004
	English	0.951
	French	0.411
	Irish	0.224
	Physics	0.412

Evaluating each of the independent variables

It was found that maths was the only subject to show a statistically unique contribution (less than 0.05) to student QCA, as shown in Table 6.

Evaluating the model

The R Square value for the above model was calculated at 32 per cent or 0.317. This suggests that 32 per cent of the variance in student QCA is explained by the results achieved in these five subjects. However, it is important to note that not all students studied these five subjects at second level. As a result, subsequent tests were conducted comparing students' Leaving Certificate Points with their QCA.

Leaving Certificate Points compared with student QCA

As most students will have studied a different combination of subjects at second level the above model does not accommodate all students. However, it does serve to highlight the importance of core second level subjects in measuring future third level performance. Second level points provide a more generic model, capable of accommodating all students, as they take into account the best six results a student received in the corresponding subjects they studied for the leaving certificate.

Leaving Certificate Points proved to have the highest positive correlation of 0.614 with their cumulative QCA.Compared to other influential variables, this is a very strong correlation.This model also resulted in an R Square value of 38% or 0.377, suggesting that 38 per cent of the variance in student QCA is explained by the second level points they received, which includes the subjects they studied.These results also proved to be statistically significant with a P value of less than 0.0005.

COMBINING INTERESTS WITH LEAVING CERTIFICATE POINTS AS PREDICTOR OF THIRD LEVEL ACADEMIC PERFORMANCE

As students' results in the realistic and investigative domain proved to be the highest influential factor in the first model and Leaving Certificate Points were the strongest in the second model, these were combined to assess their collective impact on students' third level performance. Their combined positive correlation with student QCA is shown in Table 7.

Table 7. Correlation of dominant interest types and Leaving Certificate Points with QCA

		Student QCA
Pearson Correlation	Realistic & Investigative	0.433
	Leaving Cert. Points	0.614

The collective R Square value of this new model increased to 48 per cent or 0.482, suggesting that 48 per cent of a student's third level performance is explained by leaving certificate results combined with dominant interests and resulting personality types.

DISCUSSION

This research takes a systems approach to engineering education believing that each variable affecting student performance influences the next variable. Any presage influence will inevitably influence the process, which in turn affects the product (student learning outcomes). Often, as with any system, the desired outcomes do not equal the actual outcomes. In this case a controller is incorporated to manipulate the inputs in order to obtain the desired effect on the output of the system. In this way, engineering education can be expressed as a dynamic system with more than one desirable output variables that must be maintained over a period of time (i.e. a four year degree course). Research will act as the controller and manipulate the inputs in order to obtain the desired effect on the output of the system. Once students enter university, faculty can no long influence presage variables; therefore a greater understanding of these influences is required for better-informed teaching and learning strategies to be developed.

The results of this research provide an interesting, unique and exciting insight into the presage influences on third level engineering students' academic performance. They show that even before a student embarks on a third level engineering course, 48 per cent of the variance in a future QCA will be determined by prior personal and educational factors, i.e. interests and second level education. While these factors are outside the control of third level tuition, they allow for better informed teaching and learning strategies which in turn can positively influence the process stage of student learning. Results show that students' interests influence their third level academic performance. These interests represent different personality types; those that score highest have a realistic and investigative personality. This tells us that successful engineering students like to solve problems by 'doing', they like working on projects, they like resolving complex challenges with practical solutions. This has substantial implications for the development of teaching and learning strategies and pedagogy within engineering education. It suggests that as the interests of most students lie in problem solving and working on projects, they would excel in this type of learning environment. As a result, if interests are incorporated into the teaching and learning strategies of engineering courses it is perceived that improvements in both student learning outcomes and retention rates can be achieved. Evidence of this has been demonstrated through the CDIO Initiative which employs more project-based and problem-based learning in CDIO engineering programs [25].

Not only did the realistic and investigative domains have the highest positive correlation with QCA but these domains also proved on average to be the most dominant amongst engineering students. These interests along with the subjects they studied at second level largely explain why students choose to study an engineering course at third level. Consequently this will also influence their perceptions and opinions of that course while undertaking it [19].Therefore, it is important that these are taken into account when developing teaching and learning programs for engineering courses. If these teaching strategies do not match the interests and previous learning experiences of the student they will impact negatively on student learning and retention rate.

Based on the results of this study a strong argument can also be made for making certain core subjects a compulsory entry requirement for any engineering course. Mathematics, Physics and Technical Graphics all have a strong positive correlation with students undergraduate academic performance. Conversely, failure to have undertaken these subjects to Leaving Certificate level is shown to impact negatively on university performance.

While these results provide a novel insight into the factors influencing student performance at presage level, more research in this area is required with a larger sample size and across different university programs.

CONCLUSION

This research invokes two kinds of arguments; In the first place, the study of a definite area, that of students' interests, has discovered an even greater correlation than had previously been expected between those interests and third level performance. It is believed that certain aspects of students' interests are transmitted into their work at third level affecting their performance.

In the second place, it is primarily presage activities that are responsible for the construction of a series of perceptual schemata, the importance of which in the subsequent structuring of engineering education at third level cannot, without oversimplification, be denied or rejected.

Students' interests and previous education have a very substantial influence on their future third level performance. Combined, (this study has shown) these variables account for 48 per cent of the variance in students' third level academic results (QCA).

Successful engineering students scored highly in the realistic and investigative domains indicative of a preference for problem- and project-based learning. Leaving Certificate Mathematics, Physics and Technical Graphic were also most important to future success at third level and have proved to impact on student retention rates.

Better understanding of these presage influences on student learning can lead to better informed teaching and learning strategies and, it is predicted, will positively impact student learning and retention rates.

The diagnostic tools ouitlined above can provide an accurate prediction of how students will perform in a third level engineering degree course, where no alternative extrapolation exists. However, 'the best way to predict the future is to event it', or in this case engineer it. These findings combined with those from similar research should be used to inform change in engineering education and enhance student learning outcomes

RECOMMENDATIONS

Further research into the impact of students' interests on third level performance is required and it is recommended that a larger sample cohort across other university programs be assessed.

Findings from this research suggest that in order to make further progress on retention and improving student learning outcomes, third level institutions should:

- Design engineering modules that better match student's interests, which reflect a realistic and investigative personality type, i.e. more problem- and project-based learning. Pedagogy must expose students to activities and experiences which appeal to their interests and in doing so promote a more constructive approach to learning.
- Continuously monitor and audit any new programs at the initial stages to access the impact on actual learning outcomes.
- Possibly re-evaluate the entry requirements into many of the third level engineering degree courses offered, given the high correlation of both Physics and Technical Graphics with student QCA, as well as Mathematics.
- Broaden the concept of retention to include all issues that affect student performance including both presage and process influences. While ultimately students' results at third level are often the deciding factor in whether or not the student remains in the course, attention must focus on the factors influencing student performance. This research provides further insight into these factors.
- Develop and facilitate more autonomous student learning and interpersonal skills amongst students through the use of constructivism and group work.

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