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Engineering students for the 21st century – analysis of pathways of engagement

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ABSTRACT

Work in the 21st century is vastly different from what it was as recently as 15 years ago, work is technological and multicultural, teams dominate the workplace and computers are ubiquitous (Landy & Conte, 2004). Internationally, skills shortages are being reported across both first world and developing economies (Woodridge, 2006). To combat this, a wide range of programs have been set up to cater for the needs of students interested in a career in design and engineering. These range from programs for individual students to international competitions with multimillion dollar budgets. The programs involve four distinct groups; schools, universities, professional bodies and industry. Due to the range of expectations among stakeholders, providing a measure of success is difficult. A model entitled 'Pathways of engagement' has been developed which proposes six distinct pathways of engagement between these groups. From this model, several hypotheses have been proposed from which analysis of the interaction of these groups can be undertaken and the effect of these interactions on the success of the programs noted. Comparison of this model with the work undertaken by the Great Engineering Challenge as well as a selection of existing and past programs is made.

1. BACKGROUND

Students face many challenges in the search for a career pathway which they are comfortable with. Universities have and continue to have difficulty in attracting and retaining students with sufficient ability and interest in the field of engineering and this has been well documented Adelman (1998). Programs such as the Summer Engineering Academy (SEA) and the Discover Engineering conference, run by the University of Arizona and Texas A&M University respectively are evidence of the effort tertiary education institutions have been expending to recruit able students. With a financially oriented and well defined goal in mind, these programs are perhaps missing the opportunity to educate the wider community in the crucial role engineers play in modern society, and hence are not tapping into the so called 'hidden market' - students who are unaware of the opportunities afforded them through an engineering related career.

As discussed by Douglas, et al. (2004), this is a well known problem and in response many professional organisations, insightful educators and to a lesser extent industry representatives have initiated and championed programs such as USFirst, Project Lead the Way and the Integrated Design Engineering Activity Series (IDEAS). Numerous science fairs throughout the US and in other countries such as the Intel International Science and Engineering Fair are also playing an important role in educating the wider community and have been doing so since the late 1950's (Douglas, et al., 2004).

The economic effects of ensuring continued participation by students, and ideally growth in the design profession are clearly enormous given the crucial role of infrastructure in providing accessibility to new markets, maintaining communications and distributing wealth. Reference was made to the economics effects in a speech by Vest (2005) who concluded "To compete in world markets in the so-called knowledge age, we [the U.S.] cannot depend on geography, natural resources, cheap labor, or military might. We can only thrive on brainpower, organization, and innovation." This was further discussed in the report titled "Educating the Engineer of 2020: Adapting Engineering Education to the New Century" by Clough, et al. (2004) as part of a project by the National Academy of Engineering (U.S.) to prepare for the future of engineering.

The authors of this paper have a background in high school based programs designed to engage students with design, specifically engineering. Currently the authors run the Great Engineering Challenge, which is a 'grass roots' initiative of Engineers Australia run as part of National Engineering Week. The program focuses on creating linkages with industry to expose high school students to real life engineering problems with the aim of developing practical and original solutions. Emphasis is placed on teamwork and innovation as well as developing the skills necessary to quickly and accurately communicate aspects of students' design concepts. Each year the event chooses a unique and topical theme within the realm of engineering, in this context two real life challenges are developed. Themes to date have included disaster relief, engineering heritage and road safety. In addition to the challenges, students hear from a keynote speaker and attend site tours in the afternoon. The program is designed to be decentralised with the focus being on engaging high school teachers to champion and run the program within their school. Aligned with the high school curriculum, the Great Engineering Challenge presents a novel and innovative way of addressing the existing skills shortage in Australia. Completely open source, all challenge development is published in an easy to read and accessible manner on the organisation's website – www.gec.org.au.

2. Introduction

Worldwide there has been a significant growth in engineering based high school programs, with 41% of these beginning since 2000 (Douglas et al., 2004). These programs range in annual budget from thousands to millions of dollars along with a variety of organisational structures (Douglas et al., 2004). The specific nature of why these programs started is difficult to pinpoint. The programs organised, funded and run by universities are likely to be specifically aimed at increasing enrolments at the participating university. These programs are not of particular interest to this paper as their engagement does not generally involve working with teachers, industry or professional bodies. The interaction of these four distinct groups: schools, universities, professional bodies and industry will be the focus of the paper.

As high school based programs continue to blossom, the 'industry' developed around organising and implementing these programs is reaching a crossroads. The majority of 'commercially successful' programs (i.e. those that have sustained themselves) are based on government grants (Douglas et al., 2004). Programs being solely supported by grants need to 'prove' that the program(s) are meeting the expectation of the funding requirements. Given that the pipeline from when a high school student may first engage with a program to graduation and working in industry can be as long as 10 years, soon there will be an expectation of metrics by which various programs can be assessed against a common baseline. Whilst the aim of the paper is not to address this shortcoming specifically, reference will be made to a proposed approach.

Programs run specifically by universities have a far easier job of assessing the 'success' of given programs. This is usually achieved through either exit surveys asking how likely students are to attend the university or by checking enrolments. For the type of programs this paper focuses on, only Poole et al. (2001) has developed metrics for assessment. The metrics were based on students understanding (throughout the program) and did not measure the 'success' of the program in broader terms. The assessment of student learning is an important element of any program, however the reason for running programs is of a broader significance than as to whether the specific concept of that task is understood. As also mentioned by Poole et al (2000), the measurement of metrics developed is both time consuming and costly.

The importance of developing a set of metrics that can be utilised to assess various high school based programs can not be underestimated. Any program can (and most do) claim that anecdotally the evidence suggests their program was successful. In many ways the studies undertaken by university based programs are no different. As neither of these methods use 'control groups' the results are of limited statistical validity. Whilst advanced statistical methods exist to assess these particular scenarios, no literature cited has referred to the use of these methods. Before a comprehensive set of metrics can be developed, the interaction between the four distinct groups: schools, universities, professional bodies and industry must be assessed. To facilitate this assessment six hypotheses have been developed and will be analysed using both the Great Engineering Challenge and other programs.

3. Hypotheses

The view of the authors is that the success of a program is due to the combination of relationships amongst stakeholders in the program, not necessarily an individual relationship. Hypothesis 1 states that: *the success of a program is not based on the topic (discipline), rather on the pathways of engagement.*

Further to hypothesis 1, research has shown that programs of a similar discipline with congruent goals can result in different outcomes, each with various levels of 'success'. Hypothesis 2 states that: *programs of the same discipline that utilise different pathways of engagement can result in vastly different program outcomes.*

For a program to move beyond the realm of an idea to conceptualisation and eventually to implementation the efforts of a 'champion' are required. In the context of this paper the champion is the individual who drives forward the team. Without their existence, the project would often cease to exist. There are no specific qualifications for the individual to have beyond the desire to inspire budding designers and to understand the end goal of the project (design discipline specific knowledge). Hypothesis 3 states that: *for the project to be successful, the champion needs to have experience in and a working knowledge of the program's targeted design field.*

All programs, irrespective of size are limited by the total scope for engagement. This is generally as a result of the way projects 'scale up' and the ability to find and retain key personnel. The project champion will often only have a limited set of contacts they can bring to the project. Logically these contacts are exploited first and the strength of the relationships will have a significant impact of the formation of the program. Hypothesis 4 states that: *successful projects will build on their core competencies and not try to achieve engagement using all possible pathways.* Further to hypothesis 4, hypothesis 5 states that: *projects in their initial growth stage will closely align their pathways of engagement with those of the project champion.*

As demands on teaching staff continue to increase, the expectation is that those outside the design discipline will have decreasing time to develop programs as discussed in this paper. The responsibility to develop programs is therefore with those working in the design discipline. The ability to capture and engage both teachers and the profession is key in the program expanding beyond the efforts of a few individuals. Hypothesis 6 states that: *for a program to achieve wide spread adoption, it must either fill a void in the teaching spectrum or be of such an altruistic nature that it can not be 'avoided'.*

4. DISCUSSION

To test the six hypotheses a model which outlines the various 'pathways' of engagement is presented (Figure 1). The aim of the model (entitled "Pathways of engagement") is to achieve the first step towards a logical decompartmentalisation of various programs aimed at high school students. The outcome of the decompartmentalisation is to provide a unifying framework to assist in the development and refinement of programs in various stages of their 'life cycles' as well as to begin defining and measuring metrics for the purpose of assessing success.

The Pathways of engagement model presents a non design discipline specific model for studying and understanding the pathways of engagement between the various stakeholders in programs aimed at high school students. To this end the authors consider it applicable to any design-centric program as it does not contain discipline specific knowledge, standards or methodologies. As with all models a number of assumptions are made. Projects to be analysed do not include projects run by an individual university as a recruitment tool. Nor are projects where the aim is similar to that of a 'traditional' voluntary project i.e. to simply 'do good'. The Pathways of engagement model has identified six main pathways between stakeholders. These are:

- Pathway 1: A1 ↔ B1 ↔ D1 School students can view undergraduates as role models as can undergraduates view graduates as role models. Both undergraduates and graduates can assist in programs by working with high schools students as mentors. The mentors are often the front line or 'face' of the program.
- Pathway 2: B1 → C1 & B2 → C1 Undergraduates and university staff can volunteer their time to be involved in activities co-ordinated by professional bodies.
- Pathway 3: D1 → C1 & D2 → C1 Equally graduates and discipline related staff can volunteer their time to be involved in activities co-ordinated by professional bodies.
- Pathway 4: B3 ↔ C3 ↔ D3 Colloquially referred to as the 'Bermuda triangle' the interaction of Faculty Management, Executive staff and Senior managers at Deans forums and other functions is not often understood but the effects are seen in the resulting actions or decisions.
- Pathway 5: A2 ↔ C2 General staff at a professional body tend to communicate with teachers at a day-to-day level rather than those in academia and industry who are restricted by work demands. These staff are generally hired with communication and interaction with schools as part of their job description. The uptake of email is gradually allowing further interaction between teachers and academic or industrial staff.
- Pathway 6: C1 ↔ C2 & C2 ↔ C3 General staff communicate with volunteers on the program and provide information to be passed onto teachers. Executive staff communicate with the general staff the outcomes of discussions from the Bermuda triangle.

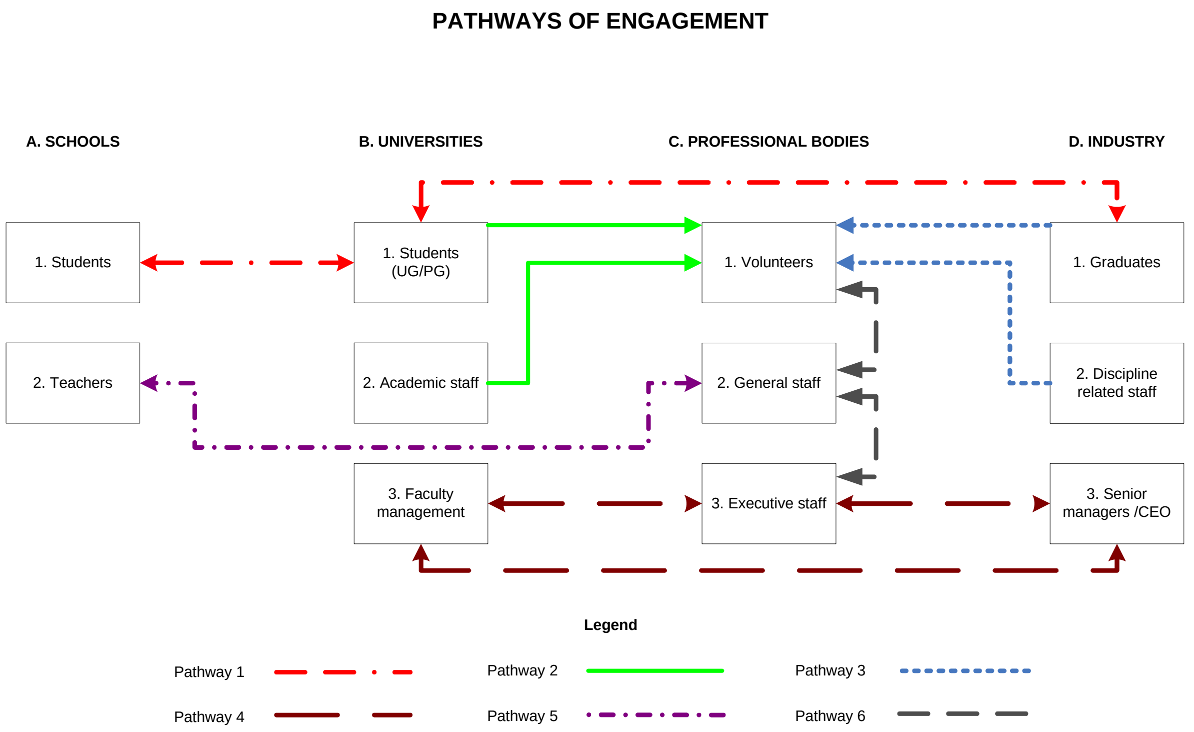

Figure 1: Pathways of engagement model

In addition to the six pathways of engagement outlined there is implicit engagement internal to each of the four distinct groups. Teachers inform students of the program, Faculty management informs Academic staff of priorities, Academic staff involve students etc. The role of internal pathways of engagement will not be addressed beyond those of the professional body already outlined.

In Australia there are a number of high school based engineering programs, the three most significant to this paper being the Science & Engineering Challenge, Re-engineering Australia Forum and the Great Engineering Challenge. The implementation of each is notably different. Science & Engineering Challenge provide a one day event that schools register to participate in and turn up to without any background work (impromptu design). The Science & Engineering Challenge is an initiative of a university with support from professional bodies increasing as the event evolves.

Re-engineering Australia Forum is a program run through industry with little to no involvement from universities and professional bodies. Teams design vehicles to be manufactured and tested on a standardised track. Both programs have regional and national finals and run largely unchanged from year to year. The Great Engineering Challenge is currently a one day program (impromptu design) with the objective being to extend the program to encompass pre and post-challenge activities. Providing the means for teachers to run the program in a decentralised manner is another hallmark of the program. The theme changes yearly and with this the challenges, keynote speaker and site tours. The Great Engineering Challenge is currently Sydney based and was an initiative of a professional body but is now run by volunteers in conjunction with industry.

Assessing the collection of the three programs outlined above against hypothesis 1 and 2 it is observed that through the utilisation of different pathways of engagement that different programs have resulted (hypothesis 2). As a result of hypothesis 2 being observed, hypothesis 1 is also observed. The success of the programs is not a result of their discipline (engineering) but rather through the utilisation of pathways of engagement. Success in this context refers to the program's continued growth and recognition of success from stakeholders.

Within each of these programs the 'champion(s)' had discipline related knowledge. The staff from the Science & Engineering Challenge are university academics, the founder of the Re-engineering Australia Forum has worked in industry and the Great Engineering Challenge is run by a postgraduate student working in industry. Each of these individuals has brought their own experience to the program and as a result have been able to focus on the actual engineering design. Examples of where programs which do not have discipline specific knowledge have failed are various engineering summer schools run by professional bodies in Australia that one of the authors has participated in. These programs have no input from discipline related staff and therefore the attitude of the staff is to find the required number of site tours and activities, disregarding the 'quality' aspect of the event which is possibly the key factor in engaging students and fulfilling the objectives of the programs. From this discussion it can be seen that hypothesis 3 is observed with the examples provided. For the project to be successful, the champion needs to have experience in and a working knowledge of the program's targeted design field otherwise it is no different to a self guided tour. The champion needs to manipulate the information available into a context that is able to engage the audience.

Naturally all programs will evolve and change over time. This is a result of both internal and external dynamics. The result of this change is generally a refocussing of efforts, not necessarily an addition of efforts. No matter the size of the program, all programs eventually reach a point of saturation where no further effort can be expanded. This is either due to the skills not being present, other programs already meeting the needs more effectively or that the expansion would be to the detriment of an established part of the program. In light of this and that the literature review found no programs that were organised and run by industry, professional bodies and universities equally draws the conclusion that hypothesis 4 is observed. Successful projects will build on their core competency and not try to achieve engagement with all stakeholders.

An international example of building on core competency is a program undertaken by the School of Engineering at Puerto Rico University during the summer of 2001 which focussed on engaging with the National Transportation Institution. González-Quevedo et al. (2002) described the program as a "complete success due in part to the enthusiastic support we received from National Summer Transportation Institute Resource Center, as well as from the University of Puerto Rico at Mayagüez administration at all levels." Faculty members and students from the university organised working sessions, field trips, visiting speakers and recreational activities to provide a complete experience designed to appeal to all the students. A theme of "Multimodal Transportation Systems" was central to the activities. Students were asked to evaluate their experience at the end of the program, and their responses indicated a very high level of satisfaction, mainly due to the wide range of activities undertaken. The organisers considered that the key objectives of the day had been met, including exposing students to the history and significance of the transportation industry and all modes of travel, advanced technology and intelligent transportation systems, including aviation and space technology, and career options in transportation design, engineering, planning, and research.

The experience of the School of Engineering at Puerto Rico University also indicates that in the initial growth stage the program aligned itself with that of the project champion. In this case working with a specific body to develop a program based on meeting the needs of the stakeholders.

Another example of this is with regard to the Great Engineering Challenge which utilises volunteer undergraduate and graduate students on the day of the event (no other high school based programs in Australia currently do to the same level). This is a result of the champion having not only contacts in the undergraduate population but the ability to be discerning with who is recruited as mentors. Both these examples support hypothesis 5; projects in their initial growth stage will closely align their pathways of engagement with those of the project champion. A further example of this is run primarily by a group of students at Northwestern University (U.S.) involving a three week classroom module which was tested between 2002 and 2004 (Olds et al., 2004).

Given the dramatic increase in the number and variety of programs being implemented, and the ever increasing pressures on teachers, the need to not 'create more work' is paramount to wide spread adoption of any program. One secondary institution noted by Poth et al. (2005) has taken the engineering design focus even further, with the whole elementary school curriculum being centred around the basic design process of plan, design, check and share. Whilst it is not necessarily realistic for every program to achieve the same level of integration as described above, the most successful programs in Australia focus on making life less difficult for the teachers, which is demonstrated by their continuation and expansion. The cost of this approach can be a loss of engagement for the students. An alternative approach is to consider how a program can meet the needs of the ever changing curriculum and therefore not sacrifice engagement for ease of use. Whilst there is limited evidence to support hypothesis 6, anecdotally it can be seen that for a program to achieve wide spread adoption, it must either fill a void in the teaching spectrum or be of an altruistic nature that it can not be 'avoided'.

5. Conclusion

The Pathways of engagement model is a unique contribution to the literature on programs run to engage high school students in design and engineering. This model is the first to demonstrate synergies between programs that may be considered incomparable. The hypotheses analysed and associated observations demonstrate that the key to successful programs is not the result of a program being of a specific discipline or having a unique feature. Successful programs involve a champion with knowledge of the discipline, alignment of the pathways of engagement with that of the champion and restriction of the team's efforts to their core competencies.

As the number of high school based programs continues to grow and the competition for government grants intensifies, the need for a common baseline of success must be established. Whilst the efforts of the organisers are rewarded through their own personal development (Olds et al., 2004), programs that require a 10 year pipeline must demonstrate results comparable with funding. The extension of the Pathways of engagement model is to identify common elements that can be used to determine success whilst taking into account the size of the program, funding received and the impact of experience on the students involved.

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