The effects of background upon engineering design expertise and producing more competent engineering design students (a Sino-occidental comparison)

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BACKGROUND
Recent research into the effects of background (national and cultural) on design thinking and practice has shown that background does indeed affect the way an individual approaches a design problem. Given the role of design within engineering and national diversity of students within many engineering courses, an understanding of how this happens can be used to inform engineering design curricular.

PURPOSE
To inform how engineering design curricula can be modified to benefit a greater diversity of students.

DESIGN/METHOD
Prior art on engineering design expertise, theory on the effects of background upon psychology (specifically comparing Sino and occidental groups) and theory on engineering design education will be reviewed. The outcomes of these reviews will then be used to draw conclusion on likely problems and potential solutions.

RESULTS
Cultural attitudes toward the nature of knowledge can affect the way a student thinks a problem should be solved, which can lead them away from developing proper engineering design expertise. Further, national background can affect what one thinks is important, and how a problem is framed, which can prevent a student from taking on engineering problems objectively to find optimum solutions.

CONCLUSIONS
Because background does affect the way one approaches a design problem it is important to note that all students will have something in their background that might help or hamper their ability to tackle design problems and develop their engineering design expertise. Helping students understand and confront this will help them to improve their engineering design ability and make the most of other educational tools used to develop design skills.

KEYWORDS
Learning style, cultural effects, student diversity.

Background

Design can be described as that part of engineering that separates it from the sciences; therefore, effective engineering design ability is essential; however, it remains a controversial aspect of engineering curricula (Dym, Wesner, & Winner, 2003). Within the context of the US Nicolai argued that without design, industry felt that universities would produce good scientists, but mediocre engineers (Nicolai, 1998). Further, the role of design in engineering education and its importance was demonstrated by Lande and Leifer while also highlight the difficulty developing design competence (Lande & Leifer, 2010).

A review article from the late 90s indicated that a major aspect of teaching design was through capstone projects (Dutson, Todd, Magleby, & Sorensen, 1997). Further, each time Dym et al. spoke of design education, they also spoke of project based learning; implicitly saying that learning design is synonymous with project based learning. This trend to use project based work in engineering to teach design was noted after conducting research into the effects of diversity within engineering design projects groups (Kress, Steinert, & Price, 2012). While finding that non-visible differences (such as cognition style), which are not the focus of this paper, could be just as significant upon team performance as visible differences (age, sex, ethnicity), they also noted that differences can often have a negative effect upon team performance due to personal conflict. The exception is a diversity of functionality, which increases communication with other functional groups or by promotes debate leading to creative solutions (Mannix and Neale). Such difficulties carry over to student groups and have been noted before (Rhamdhani, Salehi, Wong, & Kapoor, 2009). As has the need to prepare these students to work in such groups (Kiisk, 1998).

A brief review of the literature suggests that design is important; it is best learnt in a group project, but it is difficult to learn; and diversity within groups can cause negative effects. Considering this combination of difficulty and importance the author found surprisingly little research into how cultural background affects learning engineering design. This is even more surprising to the author given that engineering lecturers have expressed, in casual conversations, the difficulty they have teaching to a culturally diverse group.

Recent research into the effects of background (national and cultural) on design thinking and practice has shown that background does indeed affect the way an individual approaches a design problem (Newing, van der Waal, & Steele, 2012). This was found by interviewing a number of engineers and other designers who had worked in mixed design teams of Chinese and western designers (which included engineers). The conclusion reached was differences in background between the two groups did contribute to a change in the way they approached design problems. These differences in background were:

- cultural
- economic
- environmental

Given the role of design within engineering and national diversity of students within many engineering courses, an understanding of how background affects design thinking is worth having. Such an understanding can inform engineering design curricular and help explain difficulties that might be caused by multicultural student cohorts.

This paper aims to draw upon research in design and effects of background upon thinking to further inform how engineering design could be better taught to diverse groups of students.

Methodology

Because there is established research in related areas (design, culture and engineering education), the method used here is essentially a review of the state of the art in these key

areas and the deductive formulation of a strategy based on a consideration of those findings. Therefore, this research is qualitative and the paper is essentially a discussion piece.

First the state of the art on the understanding of engineering design expertise will be covered. Second the state of the art on the knowledge of how background influences the psychology of a person will be reviewed. The focus is upon westerners and Chinese because the author has worked as a design engineer in both situations, and has some understanding of the two, and because there is more literature comparing the two. Third, conclusions on the challenges that a student from one culture could face when learning engineering design in another culture will be extracted and put. Finally, recommendations on how this could be dealt with will be put based on knowledge found in suitable prior art.

State of the art reviews

Engineering design expertise

One of the earliest works that the author found on defining engineering design expertise came from the mid-80s, but is German. Nevertheless, that work supported other German research published in English (Ehrlenspiel & Dylla, 1993). By comparing engineering students, engineering graduates and experienced engineering designers completing a design it was found that more expert engineers (among other things):

- Put more effort into defining what their goal will be

- Generate a number of solutions and are not satisfied with the first

- Are more accurate in their analysis of a solution

- Balance the needs of major functions

The above work used a design task that was very engineering related – design a moveable wall mounted optical device. Another group carried out similar research where student and expert engineers designed a playground (Atman et al., 2007). Because this was a topic the participants were not familiar with, the use of experience was limited. No difference was found in the quality of the design between the students and experts, but it was still noticed that the experts spent more time scoping the problem. Experts were also more consistent in their overall design strategy, which included the transitioning from one design activity to another to continually clarify the scope.

One limitation with the previous papers is the expert: an engineer with experience. The definition of expertise in the literature is different from this (Ericsson, Krampe, & Tesch-Romer, 1993). Expertise is defined as that level of ability associated with world class performers. To deal with this, one paper presented the findings of interviews with two highly successful design engineers (Cross & Clayburn Cross, 1998). Reviewing the practices of these two engineers found expert design engineers:

- Use first principles

- Think systemically

- Frame problems

If scoping, framing and setting goals can be viewed as synonymous, then the above three studies support the inclusion of framing being a key element of engineering design. Systemic thinking and balancing the needs of major function would also be similar tasks and likely require transitioning so systemic thinking would also be an agreed key element of engineering design within the above three studies. Other researchers have noted that engineers must argue they have an optimum solution (Akin, 2001), which requires the use of first principles. Therefore, first principles would also be a key, and unique, element of engineering design expertise.

Background and psychology

Are western and Sino thought different; or any other types of thought? If the issues faced when teaching to a culturally mixed group are to be properly understood, then the effects of background upon how one thinks would need to be considered. As pointed out earlier, the comparison is between Chinese and western, and that will be the main focus of this review.

Some literature argues that East Asians (which includes Chinese) and westerners have been mostly separated from each other and approached life differently for thousands of years and that this has affected thought processes (Nisbett, 2004). Additionally, Weber and Hsee reviewed a considerable amount of literature (Weber & Hsee, 2000) that claims to establish a difference in thought between the two groups. Weber and Hsee however also point out that they felt some of the literature was ungrounded and stereotypical. Therefore, a preliminary review suggests a difference, but its nature needs more understanding.

As mentioned earlier, Nisbett also says the difference is thousands of years old, and dates back to early influential philosophers Confucius and Aristotle (Nisbett, 2004). Therefore, to compare of the two cultures they will be thought of as Confucian and Aristotelian. These are simple descriptions, but provide an initial comparison point suitable for this paper.

Confucianism focuses on the relationships between the individual and those around them (Rainey, 2010) as opposed to natural laws. Further, Confucius himself suggested that all he taught had come from others before him 'The Ancients', and created nothing (Yates & Lee, 1996). Therefore, it would appear that Confucius put forward conclusions that were to be accepted by others because they had come from others who were considered to be wise in such things. Based on this attitude toward the gathering and delivery of knowledge Gow et al. expect that Chinese students would treat the word of their teacher as 'golden principles which could not be challenged' (Gow, Balla, Kember, & Hau, 1996). This suggests a view that knowledge comes from within an individual and not from investigating natural phenomena. This is highlighted by what happened when the Chinese found that heavenly events were regular (conforming to a natural law). Because they were not related to the events of humans, the Chinese lost interest, and put no effort into modelling them (Nisbett, 2004). This indicates a greater tendency to value knowledge based upon who puts the knowledge forward as opposed to the argument or empirical evidence that supports it. This focus on less scientific forms of knowledge has been argued to be a contributor to China not experiencing the industrial revolution despite its history of invention (especially in the Sung Dynasty) (Nielsen, 2010).

As opposed to putting forward conclusions, Aristotle put that all truth could be found through the application of logic and the use of sound argument (de Bono, 1985). Further, it has been argued that this was the major contribution from the ancient Greeks to modern western society having science and thus being able to experience the industrial revolution (Nielsen, 2010). This implies that the source of knowledge (the individual) is less important than how the knowledge was originally gained (the method of enquiry).

If Confucianism focuses more upon the person and Aristotleanism focuses upon the method of enquiry and their influence is still felt in their respective cultures, then it would be expected that comparisons between the two groups would reveal related tendencies. One such tendency would be to argue and indeed this has been found. Yates, Lee and Shinotsuka, reported in *The Handbook of Chinese Psychology* (Weber & Hsee, 2000) that Americans were twice as likely as Chinese to critically argue against others. Another tendency would be the willingness to disregard knowledge that has been proven wrong. Yates and Lee suggest that Chinese are more inclined than westerners to use precedence and do what was done before, and follow tradition in what they call *Folk Precedent Matching* (Yates & Lee, 1996). These differences fit with the dominant philosophy of the early period of each culture, and would indicate that culture does indeed change the way one "chooses" to think, which could affect the way one develops engineering design expertise.

However, culture is only one part of one's background. Another is national, which can affect environmental background and economic background. Typically, it can be expected that the nationality of western engineers (and students) will be that of a country with developed economy. Alternatively, Chinese engineers (and students) are likely to have come from a developing economy. A noted difference between the two economies is the evaluation of saleable items (Bhawuk, 2009). In a developed country the focus is toward customisation and style. In a developing country the focus is toward functionality and low cost mass production. Mass production encourages ease of production and low cost with higher quality while customisation encourages innovation and its implementation.

It is possible to imagine how the above differences might affect the way one approaches engineering design. This in turn could be expected to carry over to how one approaches the learning of engineering design. However, without evidence that these differences do affect engineering design practices, it is only conjecture. Research has been done into a comparison between Sino and Western engineers. This was done by interviewing designers who had worked in mixed (western and Chinese) design teams in China about their experiences and observations of themselves and others during their time in these teams (Newing et al., 2012). The research found that both Chinese and western engineers tended to show characteristics pursuant to their cultural and economic backgrounds. Whereas western design engineers were more inclined to put forward ideas without fear of judgement, reframe problems or question the viability of a project suggested by management and tend toward more novel idea, the Chinese design engineers took the problems as given, were reluctant to share ideas for fear of being judged and produced designs that were acknowledged by all as easy to produce and functional. The characteristics of the engineers that led to these differences were attributed to background, and thus thought possible to change.

In summary, the two major differences between the groups that resulted in differences in engineering design were the implicitly assumed nature of knowledge and the effects of national economic background.

Teaching engineering design

The introduction cited research showing the general importance of design in engineering. However, the definition of engineering design expertise has been used implicitly. Lewis defines engineering design as the framing of the problem followed by bounded, yet divergent thinking until a problem is found and then analysed (Lewis, 2006). Lewis goes on to argue for a combination of inquiry and deign to help students use science to learn design and vice versa via problem based learning in pre-university education. The intent is basic exposure to improve technical literacy. Dym et.al focused on university level education and cited that framing needed to be taught explicitly and that students needed to be taught to cope with complex systems (Dym et al., 2003). Difficulty with teaching framing has also been noted by others (Cross & Clayburn Cross, 1998) (Adams, Turns, & Atman, 2003; Hey, Pelt, Agogino, & Beckman, 2007) and (Steele & Mann, 2011). Issues with first principles have also been highlighted within teaching engineering design expertise (Steele & Mann, 2011). However, the review found that little extra attention has been given to developing systemic thinking.

Along with problem based learning another common theme in the literature is the use of reflection to improve the design capability of engineering students (Steele & Mann, 2011) (Adams et al., 2003) (Hey et al., 2007). This need to reflect upon the experience that comes from solving a problem, which would be the outcome of combining reflection with problem based learning, indicates that design is a way of thinking or view of the world and not simply an idea or piece of knowledge that is to be accepted and then understood. This idea of design (within and without engineering) being a separate way of thinking or culture has been put forward by others (Pugh, 1982) (Cross, 2006) (Visser, 2009) (Dym et al., 2003). Therefore, the current understanding of teaching design in engineering is that it is changing the way a student thinks.

Cross cultural engineering students

Now that prior art in engineering design expertise, the effects of culture on thought and the teaching of engineering design have been covered, a foundation has been provided to conceive of issues that international students could have when learning engineering design in a western environment.

The anticipated issues for international students

Each of the two major differences revealed within the literature review on the influence of background will be linked to issues that could be faced while developing an ability to think in a manner similar to that of an expert design engineer.

The nature of knowledge

If Chinese students implicitly view knowledge as something that comes from within an individual, then they might have difficulty with the following:

- Applying first principles in novel ways. A novel application has no precedence; it is therefore the product of the student. In a culture where the quality of an idea is linked to the quality of the person who generates the idea, students would be more inclined to think that they should remember the solution that had been found earlier to a problem by a person of high esteem (the precedence matching behaviour mentioned earlier). The author has spoken informally with students who had done half their degree at the Asian campus of the university and who also made the exact comment that memory was key to their studies before studying in Australia. One of these students also expressed surprise (and maybe concern) that the content of a design subject was not exactly (in the literal sense) the same between the two campuses. This is anecdotal support only, but is congruent with the notion of some students, because of their background, thinking that design problems should have one best solution that can be taught. This notion might also reduce confidence in such a student's ability to come up with a new solution. If a student lacks confidence in themselves, then they will potentially assume that they are unable to develop a novel application and instead feel that this should be provided to them. A western student might still lack confidence, but potentially assume that it is a lack of practice that is the main issue.

- Framing problems for better solutions. If a student feels that the best understanding of a problem would come from a teacher or anyone else deemed to be of a higher status, then they would likely automatically believe that the problem should be left as presented and no framing would be performed. A student from a Confucian background would likely have had little experience framing, and lack practice. They could also feel uneasy doing this; it would be disagreeing with one who is senior.

- Limitation in systemic thinking. To understand the implications of a decision upon a system, one needs to know that the system is. This could require independent thought by the designer to determine what the limit of the system is. Does it include only the mechanism being worked upon, the product it is part of or the society that will need to use it? Each design project will be different from others in this sense. However, it is possible that different decisions within a certain design project will also have different systemic issues. Further the system that needs to be considered for each project is different. Elements of the system might also be outside of the explicit field of domain knowledge of an engineering student as well. If a student feels that they should not be taking on problems that involve knowledge they have not been taught, then they might choose to exclude related elments from the system they think they should deal with. This could be a decision that is not ideal for finding a suitable design solution.

Influence of economics

Due to economic background, compared to other students, western students are more likely to be interested in designing something novel, possibly for the sake of novelty, as opposed to something that is practical and economical. Therefore, a non-western student in a predominantly western engineering design educational environment (which could include the lecturer) will potentially:

- Develop less creative designs than expected. A creative solution would introduce more uncertainty which could be a risk when it comes to economical production or implementation.

- Reframe a problem differently from what is expected. With a focus on efficiency and functionality, a non-western student will perhaps view the underlying problem in a different context, and thus choose a different problem to solve. It is worth noting that a western student would potentially have the same issue in a different context, and the real issue here is that all students need to ensure that they do not let their background affect their framing to excess.

Improving teaching for diverse groups

The main issues that need to be dealt with, as identified in this paper, are:

1. The tendency to think that knowledge comes from within, which results in the respective students thinking they should remember solutions to specifics problems found by those who went before. This limits the tendency to reframe problems, which includes understanding and defining the system to be considered, and applying first principles as required; not when it is obvious.

2. The tendency to frame based on what one thinks is important due to background. The primary example is national economic background. However, other backgrounds might have a similar effect. When asked about their experience in multicultural design teams a designer noted that designers from rural areas had a greater sense of practicality because they had to resolve a number of similar issues in the past (Newing et al., 2012). If one's background can affect the way one frames a design problem, then each engineering student (and academic) will need to realise this to produce unbiased and optimal design solutions.

The above two issues are related to how one thinks about design problems. Therefore, design education is about changing the way a student thinks. Changing the way a group of people think is a social change. One of the keys to bringing about social change is charismatic leadership (Fiol, Harris, & House, 1999). In their highly cited work, Fiol et.al. argue that the first step in bringing about social change is 'Frame Breaking'. The leader (engineering design lecturer) confronts the undesired norm and reduces its value. The reduction is brought about by using negative words such as 'no' and especially 'not'. Within the context of engineering design, a lecturer might say words to the effect of:

- Engineering design is not about remembering a solution to a problem when you see it

- Do not rely solely on past experience to guide your solutions

Such statements should help students break away from limiting ideas they might have when it comes to engineering design. Then when combined with problem based learning and reflection they will be freer to investigate new ways of thinking suited to engineering design.

Conclusion

Different backgrounds encourage different thinking. This will influence approaches to engineering design problems and learning engineering design. However, because this is a result of background it can be changed. The implication is that engineering design

academics will need to bring about such a change, which is much like a social change. Charismatic leadership practices, such as frame breaking, can help with this.

Limitations and further research

This paper has focused only on a comparison between western and Chinese backgrounds to reach conclusions on how a diverse group of students can be helped to increase engineering design expertise. Other groups might have issue separate from those raised above, and studying these would be of interest. Further, the comparison has been based on literature only, and the conclusions are deductive inference on that basis only. Finally, the compounding effects of individual learning style (within a culture) have also been ignored. Empirical investigation, which is recommended for further work, would likely provide more useful information.

References

Adams, R. S., Turns, J., & Atman, C. J. (2003). Educating effective engineering designers: the role of refelctive practice. *Design Studies, 24*, 275-294.

Akin, O. (2001). Variants in Design Cognition. In E. C., W. Newstetter & M. McCracken (Eds.), *Design Knowing and Learning: Cognition in Design Education* (pp. 105-124): Elsevier Science.

Atman, C. J., Adams, R. S., Cardella, M. E., Turns, J., Mosborg, S., & Saleem, J. (2007). Engineering Design Processes: A comparison of Students and Expert Practioners. *Journal of Engineering Education*, 359-379.

Bhawuk, D. P. S. (2009). Intercultural Communication in a Dynamic Environment: Preparing Managers of Developing and Developed Countries Using Cultural Standards. *Progress in Development Studies, 21*(2), 161-181.

Cross, N. (2006). *Designerly Ways of Knowing*. London: Springer-Verlag.

Cross, N., & Clayburn Cross, A. (1998). Expertise in Engineering Design. *Research in Engineering Design - Theory, Applications, and Concurrent Engineering, 10*(3), 141-149.

de Bono, E. (1985). *Six Thinking hats*: Penguin Books.

Dutson, A. J., Todd, R. H., Magleby, S. P., & Sorensen, C. D. (1997). A review of Literature on teaching Engineer Design Through Project-Oriented Capstone Courses. *Journal of Engineering* Education, 17-28.

Dym, C. L., Wesner, J. W., & Winner, J. (2003). Social dimensions of engineering design: observations from Mudd design workshop III. *Journal of Engineering Education*, 105-107.

Ehrlenspiel, K., & Dylla, N. (1993). Experimental Investigation of Designer's Thinking Methods and Design Procedures. *Journal of Engineering Design, 4*(3).

Ericsson, K. E., Krampe, R. T., & Tesch-Romer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review, 100*(3), 363-406.

Fiol, C. M., Harris, D., & House, R. (1999). Charismatic leadership: strategies for effecting social change. *Leadership Quaterly, 10*(3), 449-482.

Gow, L., Balla, J., Kember, D., & Hau, K. T. (1996). The learning approaches of Chinese people: A function of socializayion processes and the context of learning? In M. H. Bond (Ed.), *The Handbook of Chinese Psychology* (pp. 109-123). Hong Kong: Oxford University Press (China) ltd.

Hey, J., Pelt, A. V., Agogino, A., & Beckman, S. (2007). Self-reflection: lessones learned in a new product development class. *Journal of Mechanical Design, 129*(7), 668-676.

Kiisk, L. M. (1998). Culture Shock: Preparing Students for Globalization of the Construction Industry. . *Journal of Constuction Education, 3*(3), 213-222.

Kress, G., Steinert, M., & Price, T. (2012). *Cognition as a measure of team diversity*. Paper presented at the Interdisciplinary Engineering Design Education Conference, Santa Clara, CA, USA.

Lande, M., & Leifer, L. (2010). Difficulties Student Engineers Face Designing the Future. *the International Journal of Engineering Education, 26*(2), 271-277.

Lewis, T. (2006). Design and Inquiry: Bases for an Accommodation between Science and Technology Education in the Curriculum? *Journal of research in science teaching, 43*(3), 255 - 281.

Newing, A., van der Waal, S., & Steele, C. (2012). *The effects of background upon engineering design expertise – a Sino occidental comparison*. Paper presented at the International Conference on Advanced Design and Manufacturing Engineering, Taiyuan, Shanxi, China.

Nicolai, L. M. (1998). Viewpoint: An Industry View of Engineering Design Education. *International Journal of Engineering Education, 14*(1), 7-13.

Nielsen, J. K. (2010). The flower the didn't bloom: why did the industrial revolution happen in Europe and not in China? *Journal of Chinese Economic and Business Studies, 8*(1), 23-44.

Nisbett, R. E. (2004). *The geography of thought: How Asians and westerners think differently and why*. New York: Free Press.

Pugh, S. (1982). Design - the integrative-enveloping culture - not a thrid culture. *Design Studies, 3*(2), 93-96.

Rainey, L. D. (2010). *Confucius and Confucianism: The Essentials*. Chichester: John Wiley & Sons, Ltd.

Rhamdhani, M. A., Salehi, K., Wong, Y. C., & Kapoor, A. (2009). *Group work as a vehicle for engaging students into the process of broadening perspectives and building intercultural skills*. Paper presented at the proceedings of the 2009 AaeE conference, Adelaide Australia.

Steele, C., & Mann, L. (2011). *Developing engineering design expertise though reflection*. Paper presented at the AAEE Conference, Fremantle, Western Australia,.

Visser, W. (2009). Design: One, but in different forms. *Design Studies 30*(3), 187-223.

Weber, E. U., & Hsee, C. K. (2000). Culture and Individual Judgement and Decision Making. *Applied Psychology: An international review, 49*(1), 32-61.

Yates, J. F., & Lee, J. W. (1996). Chinese Decision-making. In M. H. Bond (Ed.), *The Hanbook of Chinese Psychology* (pp. 338-351). Hong Kong: Oxford University Press (China) Ltd.

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