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Interdisciplinarity in design education: understanding the undergraduate student experience

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Abstract Interdisciplinarity is becoming a critical issue of concern for design schools across East Asia in their attempts to provide industry graduates with the skills and competences to make creative contributions in a global economy. As a result, East Asian higher education institutions are aggressively endeavouring to provide interdisciplinary undergraduate curriculum that combine traditional designerly skills with engineering knowledge and methods. The current study takes an interdisciplinary undergraduate course as case-study to examine how the pedagogic strategy of team teaching influences student learning experience. Two surveys of student learning were conducted for this research purpose. The first provided an indication of the holistic student learning experience, while the second explored the conditions of team and non-team teaching as influence upon learning experiences specifically. Results showed how students taught by a single instructor provided a more positive overall opinion of course quality and experienced significantly more encouragement to participate compared to team taught respondents. However, findings also indicated how team teaching significantly increased the students' experience of a balanced contribution from different disciplinary perspectives and how the team teaching approach was significantly more effective in providing students with greater opportunities to understand the relevance of the different disciplines to the course subject. We conclude with a discussion of results in terms of the effective use of team teaching at undergraduate level as strategy for interdisciplinary learning experiences.

Keywords Interdisciplinarity · Student experience · Team teaching · Design thinking

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Introduction

Interdisciplinary professionalism is emerging as a critical issue for achieving outstanding performance in a knowledge-based society (Kang 2008). However, the higher education system in Korea may historically be described as an attempt to dig a narrower uni-disciplined field deeply at a single point. As a consequence of the advancement of individual majors through departmentalised specialisation, the barriers between departments continue to increase. Many now agree that disciplinary learning in design, justified through subject specialty and the tendency to focus on branches of education, has reached a critical tipping point (Mok 2009; Norman 2010; Norman and Klemmer 2014).

However, higher education is now endeavouring to drive towards pedagogic interdisciplinarity as a means to foster competitive creativity (Kim et al. 2012). This is increasingly true of East Asian design and engineering education at both under and post graduate levels. For example, in the Republic of Korea, The Korean Ministry of Education Science and Technology (MEST) has initiated the World Class University to establish new interdisciplinary academic projects (The Korean Ministy of Education 2008). The programme is described as giving priority to interdisciplinary studies that consolidate the fields of basic sciences, humanities and social sciences, citing a need for international scholars to cultivate interdisciplinary studies as a means to foster creativity and enhance national, higher educational and industrial competitiveness within inter-disciplinary fields. Although the will to provide opportunities for interdisciplinary education is clear, there remains little consensus on how interdisciplinary pedagogic approaches may best benefit the student learning experience. How does student learning compare between conventional, single discipline approaches to teaching and interdisciplinary strategies?

The current study investigations team teaching as undergraduate pedagogic approach within the authors' interdisciplinary design school [School of Design and Human Engineering, UNIST (Ulsan National Institute of Science and Technology)]. To achieve this, we run a comparative analysis of student experiences between team and non-team teaching in two cycles of the same undergraduate course entitled Design Thinking. Findings provide evidence to indicate the strengths and limitations of the approach in terms of the student learning experience. Recommendations for the strategic use of team teaching to foster interdisciplinary skills and knowledge through effective learning experiences within design education are finally discussed.

Pedagogic interdisciplinarity

An investigation of interdisciplinarity is complicated by disagreement on a clear definition of what constitutes interdisciplinary education. As such, progress towards establishing approaches to the assessment and validation of interdisciplinary strategies as catalyst for interdisciplinary learning is limited. However, efforts have been made to provide a theoretical grounding for the investigation of interdisciplinary pedagogy. For example, Mansilla and Gardner (2003) offer three indicative criteria for assessing interdisciplinary competence: work that is well grounded in the disciplines, work which advances student understanding through integrating more than one disciplinary lens and work which illustrates critical awareness in the means by which disciplinary knowledge is synthesised. Mansilla and Gardner (2003) further argue that the success of interdisciplinary integration may best be measured by the degree to which it achieves these three aims.

Similarly, Lattuca et al. (2013) provide criteria for the measurement of interdisciplinary competences among undergraduate design engineering students. The first, *Awareness of Disciplinarity*, draws upon Mansilla and Gardner (2003) notion of work that is well grounded in the disciplines upon which it is drawn. This notion rests upon the idea that a certain level of disciplinary knowledge is required to effectively integrate the perspectives, methods and practices of two or more disciplines to achieve a specific goal. *Appreciation of Disciplinary Perspectives* is described as the process of fostering disciplinary knowledge; moving from a general knowledge to more specific knowledge of how elements inform insights into the problem. *Appreciation of non-disciplinary perspectives* is described as an ability to appreciate knowledge which transcends disciplinary understanding to solve often complex problems. *Recognition of Disciplinary Limitations* is a means through which interdisciplinary competences may be measured. Here Lattuca et al. (2013) describes a critical reflection upon and awareness of one's own field of study as fostered by knowledge of other disciplines. *Appropriateness of Interdisciplinarity* is an ability to solve different problems in various situations. Students are provided opportunities to develop the aptitude to effectively evaluate the effectiveness of interdisciplinary work. *Finding Common Ground* considers an ability to dynamically modify one's own perspectives, world view and expectations to accommodate those of others. *Reflexivity* is described as an ability to reflect upon one's own choices in the definition of a given problem. Finally, *Integrative Skill* is an ability to synthesise knowledge in order to provide a more comprehensive understanding of the problem together with possible solution directions.

Repko (2012) calls for a distinction between multidisciplinary approaches and truly interdisciplinary work, describing multidisciplinary education as the juxtaposition of two or more disciplines. Lattuca (2001a, b) provides the analogy of the fruit bowl compared to the fruit smoothie to help illustrate a difference between multidisciplinary and interdisciplinary research and education. Multidisciplinary studies are described as the positioning of disciplines alongside one another (different fruits in the bowl), wherein the fruits and their position are distinct and separate. This is contrasted with the smoothie; the fine blending of fruits to produce a recipe for closely integrated interdisciplinarity.

This strictly dichotomous approach has however been criticized for its inability to account for a continuum of interdisciplinary endeavors (Lattuca 2001a, b). That is, interdisciplinary may exist within shades of grey. One end characterised by as little as informal conversations between faculty and students from different disciplines of study; in contrast to more formal collaborative approaches, such as team teaching. In this respect the current study falls into the latter, more formalized dimension of the interdisciplinary spectrum in the examination of team teaching as strategic approach to interdisciplinary undergraduate design education.

Conceding the contested meaning of interdisciplinarity indicated in the literature, we adopt Klein and Newell's (1998) definition as a workable construct to define the scope of interdisciplinary education for the purposes of our investigation:

> A process of answering a question, solving a problem, or addressing a topic that is too broad or complex to be dealt with adequately by a single discipline or profession...and draws upon disciplinary perspectives and integrates their insights through construction of a more comprehensive perspective.
>
> (Klein and Newell 1998, p 393–394)

Interdisciplinarity and design education

A growing body of work has explored interdisciplinarity in design education (Adams et al. 2003; Lattuca et al. 2013; Lattuca and Knight 2010; Strong 2012). For example, Lattuca and Knight (2010) investigate perceptions of engineering design education to discuss the ways in which different stakeholders understand interdisciplinarity; drawing out possible implications for interdisciplinary pedagogic strategies. Other studies have aimed to provide tools, methods and approaches to facilitate interdisciplinary in design and engineering. Carulli et al. (2013) discuss current issues in the application of educational tools and methods that attempt to integrate product design and engineering, developing and validating an integrated framework for interdisciplinary education. Lattuca et al. (2013) present a series of scales through which interdisciplinary competences may be measured; validated through their application in a survey of interdisciplinary abilities among design engineering students.

Other studies of interdisciplinary education in design are based upon descriptive accounts of interdisciplinary approaches to course development (Jaeger et al. 2013; Kim et al. 2012; Oehlberg et al. 2012; Strong 2012; Thompson 2009a, b; Yim et al. 2011). As an example, Kim et al. (2012) provide a descriptive assembly of design and engineering courses at undergraduate level. Through both quantitative and qualitative assessment of their interdisciplinary programme, students were found to possess increased information sourcing and resource application skills. However, due to a lack of time in learning a depth of core competencies in either of the distinct disciplines of design and engineering, Kim et al. (2012) indicate the ways in which students suffered from a lack of confidence in the depth of their disciplinary knowledge and skills.

Further work has explored the concepts, ideas and philosophies that underpin interdisciplinary integration. For example, Kaygan (2014) examines gender implications for interdisciplinary relations between design and engineering students, indicating the ways in which relations are constructed through symbolic dualisms—real/arty, objective/subjective, technological/aesthetics. Highlighting the culturally informed drivers of opinions towards design and engineering, Kaygan (2014) study identifies underlying attitudes as an influence upon the success of interdisciplinarity. In a related way, Tolbert and Daly (2013) explore engineering students' holistic perceptions of the concept of design creativity within an interdisciplinary context. Their investigation identifies a set of criteria for measuring attitudes towards creativity: instructor competencies, project constraints, perceived risks associated with exploring creative ideas and course structure.

Our review indicates research on interdisciplinary design education may broadly fall into three areas of study. Prescriptive studies aimed at the provision of tools and methods to describe, measure and assess interdisciplinarity (Carulli et al. 2013; Lattuca et al. 2013; Mansilla and Duraising 2007; Mansilla and Gardner 2003). Descriptive investigations, often employing educational case-studies as means to present and describe examples of interdisciplinary design pedagogy (Jaeger et al. 2013; Kim et al. 2012; Lattuca and Knight 2010; Oehlberg et al. 2012; Strong 2012; Thompson 2009a, b; Tolbert and Daly 2013; Yim et al. 2011), and works which aim to analyse the conceptual factors, principles or frameworks that underpin interdisciplinary education (Adams et al. 2003; Kaygan 2014; Lattuca 2001a, b; Lattuca et al. 2004; Newell 2001). The scope of the current study aligns with the third approach in its empirical examination of how team-teaching, as strategy for pedagogic interdisciplinarity at undergraduate level, influences the student learning experience.

Student learning experiences

Four types of learnt knowledge can be identified: declarative knowledge, knowing something or knowing what; procedural knowledge, knowing how; schematic knowledge, knowing why and strategic knowledge; knowing the application of when, where and how (Kolb 2014). Higher education institutions in East Asia are currently inclined to focus upon declarative knowledge for a specific domain and then have a tendency to convert this to procedural knowledge. However, rather than a capacity to apply discipline specific competences, the global era now requires the creative ability to look at complex problems from broader, diversified perspectives (Suh and Park 2009). In the context of design pedagogy, an understanding of the potential benefit of creatively strategic knowledge has prompted debate upon how design education should best respond to the changing requirements of industry on an increasingly competitive world stage. In an influential series of publications by Norman (2010) and Norman and Klemmer (2014), interdisciplinary strategies for the convergence of skills and knowledge in design pedagogy is elevated to of critical importance if design education is to keep pace with the dynamically changing demands of industry and society.

In terms of interdisciplinarity and student learning, using a 16 week integrated design studio class as case-study for interdisciplinary education, Lee (2014) indicates the importance of preparation and increased effort in the successful facilitation of interdisciplinary learning experiences. This is because educational effectiveness and student learning appear to be more sensitive to failure in an interdisciplinary learning context compared to conventional, discipline specific design studio courses (Lee 2014). Likewise Lattuca et al. (2004) discuss limitations in an understanding of how interdisciplinary pedagogic strategies influence student learning experience. Through a review of theories of learning the study provides a set of questions for further work on the strategic use of interdisciplinary strategies. The report concludes with a key question for the effective development of understanding towards interdisciplinarity in the student learning: Are gains in students' knowledge and skills attributable to the interdisciplinary nature of courses? Their preliminary analysis indicated a combination of interdisciplinary course curricula and intentional pedagogy stands the best chance of fostering successful student learning than either in isolation.

In a further work, Oehlberg et al. (2012) discuss how an interdisciplinary approach provided opportunities for students to broaden their own learning experiences. In a case-study of a human-centred design course, benefits for student learning included increased breadth of experience through opportunities to engage subjects adjacent to their majors. Moving a step further, Mendoza et al. (2007) suggest how the experience of interdisciplinarity provided design students new identities to advance the dynamic requirements of a fast moving profession. In contrast however, Kim et al. (2012) describe how students taking interdisciplinary majors experienced a loss of identity, related to a lack of discipline specific education.

Contributing to what remains a limited body of work exploring interdisciplinary education (Lattuca et al. 2004), the current study indicates the strengths and limitation of the team teaching approach in terms of student learning experiences through case-study analysis of interdisciplinary team teaching in design.

A case of team teaching in design

The current study examines the influence of interdisciplinary team teaching upon the student learning experience within the authors' home institution (UNIST). The use of the authors' institution as case-study is particularly appropriate due to its unique approach to interdisciplinary education at both under and postgraduate levels, both within schools and departments and across the institution as a whole (Kim et al. 2012). The authors' design school comprises departments of industrial design and human systems engineering, with associated faculty from a diversity of backgrounds including industrial design, engineering systems design, human factors/ergonomics, HCI (human computer interaction) and BCI (brain computer interaction). This mix of staff provides opportunities for a diverse education at both under and postgraduate levels. Students are encouraged to build their own learning experience through a combination of engineering, ergonomics and design-based courses within the framework of a major/minor system. Also, uniquely within the Korean context, the institution's programmes at both under and postgraduate level are offered exclusively in English.

Within this interdisciplinary context, the authors' design school has for 2 years running offered three required school level courses (one for each year group). These three courses are required for all undergraduate students majoring or minoring within the school at either the industrial design or human systems engineering departments. In offering the three courses, we have attempted to cut across traditional disciplinary boundaries by providing strategic course curriculum related to the three main fields present within the school (industrial design, human factors/ergonomics and engineering systems design). To facilitate the interdisciplinarity within the three courses, co-teaching between a design, an engineering and human factors instructor was used to potentiate interdisciplinary learning experiences.

The current study reports an analysis of a second year required school level course entitled Design Thinking. The course was originally designed to provide students with introductions to the three disciplines present within the school together with insight into how the three work together to potentiate design thinking and successful new product development. The course's description is provided below.

> Reflecting the integrated nature of the School of Design and Human Engineering at UNIST, this course offers introductions to Integrated Industrial Design, Affective and Human Engineering and Engineering Systems Design. What is a designer, engineer or ergonomist? What roles and responsibilities do these three disciplines play in the development of new products and systems? How does the integration of knowledge from across these three fields result in human centred, innovative and engineered solutions to often ill-defined design problems. Students learn some of the fundamental design methodologies of industrial design, human factors engineering and engineering design through lectures, studio classes, practical assignments and presentations. Learning objectives content will be applied and tested through studio sessions and a practical design project.
>
> (Affairs 2013)

In the course's first cycle, team teaching by three instructors (industrial design, human factors, and engineer) was employed in an attempt to facilitate interdisciplinary learning experiences, knowledge and skills acquisition. The industrial design instructor was a full time faculty member, had 7 years industry experience and 6 years teaching experience at both under and post graduate level at the commencement of the course's first cycle. The human factors instructor also possessed 7 years industry experience together with 5 years of prior teaching experience. Likewise, the engineering faculty possessed 10 years of research experience in his respected field of expertise together with 3 years teaching experience. All three team members had obtained doctoral degrees in their respective fields outside of Korea. In this way we may say that the course instructors were well equipped to teach their respective disciplines and had previous experience of developing their own course context and pedagogic approaches to student leaning needs. Thus, the instructors were well prepared to teach in their own discipline, although it is less clear to what extent this previous experience supported the current interdisciplinary endeavour.

However, in the course's second cycle, due to changes within the school, the human factors and engineering instructors were removed from course instruction, leaving the single industrial design professor as the sole instructor for the course. The current study provides a comparative analysis of student learning between the team taught and non-team taught course cycle.

Methods

Survey

Survey was used as an approach to examine the influence of interdisciplinary team teaching upon student learning experiences. For this research purpose two surveys of student learning were conducted. A first survey (S1) was designed to provide an indication of the holistic student learning experience. A second survey (S2) focused upon the more specific condition of team and non-team teaching as influence upon learning experiences.

Table 1 Survey 1 (S1) sections, questions and Likert-scale response items

Survey section	Survey question no	Likert-scale response items
Overall	Q1. Rate the overall quality of the course Q2. Rate the instructor's overall teaching effectiveness Q3. Overall, I would recommend this instructor to others	(1) Strongly disagree (2) Disagree (3) Neutral (4) Agree (5) Strongly agree
Teaching	Q4. My instructor gave well-organised presentations Q5. My instructor used good examples and illustrations Q6. My instructor stimulated my interest in the subject Q7. My instructor was knowledgeable on course topics Q8. My instructor treated students with respect Q9 My instructor encouraged me to ask questions and to participate in class discussions	(1) Strongly disagree (2) Disagree (3) Neutral (4) Agree (5) Strongly agree
Learning	Q10. Course assignments contributed to my learning Q11. The amount of reading/homework was reasonable Q12. Feedback on assignments was helpful Q13. My instructor's use of instructional technology increased my overall learning in this course Q14. The level of difficulty of this course was appropriate for me Q15. Exams accurately assessed what I learned in this course	(1) Strongly disagree (2) Disagree (3) Neutral (4) Agree (5) Strongly agree

S1 was administered through an online institutional learning environment. Students taking Design Thinking during the first (team taught) and second (non-team taught) course cycles were required to complete S1 within a week of course completion, but prior to obtaining their course grades. This requirement was built into the S1 process to avoid the effect of grade as influence upon response. S1 consisted of three sections, for a total of 15 questions. For each question, student responses were recorded through five-item Likert-scales. Table 1 presents the three survey sections (Overall, Teaching, Learning), 15 survey questions, and corresponding five-item scales.

Each of the 15 questions required completion in order for student respondents to submit S1 through the digital learning environment

A second survey (S2) was designed to gather responses more specifically related to interdisciplinary student learning experiences during the team and non-team taught courses. As with S1, S2 was administered within a week of course completion, but prior to the students' course grade publication. Unlike S1, S2 used a varied set of closed response questions, including five-item Likert-scale, check-box and Yes/No response items. The 12 questions used in S2, together with response items, are illustrated in Table 2.

Responses from both cycles of the Design Thinking course, indicating student experiences of team teaching (cycle one, S1 and S2) and non-team teaching (cycle two, S1 and S2), were archived for later comparative analysis.

Participants

S1 and S2 were administered at the end of two Design Thinking courses consecutively run over two academic cycles. In the first cycle the course was team-taught by three academics within the authors' host institution; one from the field of industrial design, another from a

Table 2 Survey 2 (S2) questions and Likert-scale response items

Survey question no	Response Items
Q1. The course offered clear introductions to ID, HF and ED Q2. The course helped me to understand the relationship between ID, HF and ED	(1) Strongly disagree (2) Disagree (3) Neutral (4) Agree (5) Strongly agree
Q3. The class taught me how ID, HF and ED work together in the design development process	Check box
Q4. The course was equally weighted between ID, HF and ED	
Q5. The different lectures did not seem to provide a clear message about design	
Q6. The knowledge, skills and methods provided in the lecture did not relate well to my design work	
Q7. The course helped me to understand the role of design and how it relates to ED and HF in design thinking	
Q8. ID, ED and HF did not integrate well on the course	
Q9 The Design Thinking course is helpful to me and my own studies, at (name of institution)	
Q10. Would you recommend this course to an undergraduate design student?	Yes/no
Q11. Would you recommend this course to an undergraduate human factors student?	
Q12. Would you recommend this course to an undergraduate engineering student?	

ID industrial design, *ED* engineering design, *HF* human factors human factors and ergonomics background, and a third from systems engineering. In the second cycle, the same Design Thinking course was run again at the same school within the same institution for the same student year group (Year 2, 4 year undergraduate degree programme). However, unlike cycle one, responsibility for the cycle two course was taken by the industrial design faculty alone, with no input from engineering or human factors instructors.

The student cohort of both cycle one and two reflected the interdisciplinary nature of their home institution. Approximately one third were second year undergraduates majoring in industrial design. A further third were studying ergonomics and human factors, with a final third majoring in engineering systems design. At the end of the first course cycle, 72 students completed S1 ($n = 72$) and 44 ($n = 44$) completed S2. In cycle two, 74 students responded to S1 ($n = 74$) and a further 40 ($n = 40$) responded to S2. In order to aid statistical analysis of results, two respondents were randomly removed from the data-set of cycle two of S1 and a further four were removed from cycle one of S2. This resulted in an identical number of respondents for both S1 and S2 across the two cycles of the Design Thinking course. Table 3 illustrates the number of student respondents for S1 and S2 across cycle one (team) and cycle two (non-team) taught courses.

Survey procedure and data analysis

Both S1 and S2 were online, self-administered surveys. In each case, student respondents were provided with an explanation of the purpose of the surveys (to provide information related to holistic course experience, S1 and student experience of interdisciplinary learning, S2). An indication of time to survey completion was also provided (approximately 10 min). Finally, respondents were advised that no personal information would be taken and that their identity would not be revealed in any future publication of survey results. In both course cycles one and two, respondents completed the surveys by answering questions in sequential order (questions 1–15, S1 and 1–12, S2). All questions were mandatory, requiring a response before survey submission.

In the first team taught academic cycle, S1 and S2 were administered online within the week after course completion (16–23rd May, 2013). In the second non-team taught cycle, S1 and S2 were again administered over a 7 day period immediately following course completion (20–27th June, 2014). No completion time data was recorded for S1 (2013, 2014). In the case of S2, the average time for completion in cycle one (team taught), was 07:44. In the second cycle (non-team taught) average completion time was similar at 07:30.

In order to examine the influence of team teaching upon student learning experience, the two data-sets from S1 and S2 were subjected to statistical analysis. To achieve this, in the case of the 15 questions of S1, independent-means t tests ($p = < .05$, 2-tailed) were run to

Table 3 Student respondents for S1 and S2 across cycle one (team) and cycle two (non-team)

Survey	Course type	Student respondents (adjusted)
S1 (survey 1) (Holistic course experience)	Team taught (cycle 1)	$n = 72$
	Non-team taught (cycle 2)	$n = 72$
S2 (survey 2) (experience of interdisciplinarity)	Team taught (cycle 1)	$n = 40$
	Non-team taught (cycle 2)	$n = 40$
	Total response set	$n = 224$

examine differences between student responses from the team (cycle one) and non-team (cycle two) courses. In the case of S2, the first two Likert scale questions (Table 2, questions 1 and 2) were analysed through independent-means *t* tests to examine differences between the conditions of team and non-team teaching ($p = < .05$, 2-tailed). The categorical data in question 3–12 derived from survey responses (checkbox questions 3–9, yes/no questions 10–12) was subjected to frequency analysis to examine any significant differences in frequencies of yes/no response and box-check responses between the team and non-team taught samples. To achieve this, *Pearson's Chi square* test ($p < .05$, 2-tailed) was run with the independent variables as teaching condition and dependent variables as response to S2 questions 3–9 and 10–12 cross tabulated between team and non-team teaching.

Results S1 (survey one)

The first three questions of S1 were designed to capture responses related to the students' holistic experience of the Design Thinking course including course quality (Q1), teaching effectiveness (Q2) and student recommendation of course instructor(s) to peers (Q3). Table 4 presents the three questions, condition mean scores for each question, *t* values and 2-tailed significance value (independent-means *t* test).

Results of the independent means *t* test showed mean response to the overall quality of the course between team teaching ($M = 3.7$, $SD = .87$) and non-team teaching ($M = 3.9$, $SD = .70$) was higher in the non-teaching condition. However, this difference was not significant [$t(142) = 1.902$, $p > .05$]. Question two of S1 asked respondents to assess teaching effectiveness within the course. Again, mean responses from students from the non-team taught class were more positive ($M = 3.9$, $SD = .80$) than those exposed to team teaching ($M = 3.7$, $SD = .94$). This result was, however, also not found to be significant [$t(142) = 1.629, p > .05$]. Finally, survey question 3 asked if students would be inclined to recommend the course instructor(s) to others. As with the two previous questions, student mean response was more positive in the non-team teaching condition ($M = 3.8$, $SD = .90$) compared to team teaching ($M = 3.7$, $SD = .94$), although this result was again not significant [$t(142) = .724$, $p > .05$]. From these results it appears the students who were taught by a single instructor may have had a more positive overall opinion of the quality and effectiveness of the course. However, responses between the groups were not found to be significantly different, indicating the influence of the non-team taught approach upon a holistic experience of course quality and effectiveness and instructor performance was somewhat marginal.

S1 Section two focused specifically upon the instructor(s) teaching performance. Table 5 illustrates the six questions asked within S1's second section (Q4–Q9), the

Table 4 S1 (survey 1), section one, questions 1–3

	Condition mean		*t* value	Sig.(2-tailed)
	Team	Non-team		
Q1. Quality of course	3.7	3.9	1.902	.059
Q2. Teaching effectiveness	3.7	3.9	1.629	.105
Q3. Recommend instructor(s)	3.7	3.8	.724	.471

condition mean scores for each question (Team and Non-Team), *t* values and 2-tailed significance value (independent-means *t* test).

Question 4 asked of the instructors' organisation and presentation of course material. Students who experienced the team taught class recorded a lower mean presentation score ($M = 3.9$, $SD = .85$) compared to students in the non-team taught condition ($M = 4.1$, $SD = .76$). The more positive non-team taught student mean response was, however, not significant [$t(142) = 1.962, p > .05$]. This indicated students in the non-team taught class experienced better organised presentations compared to the team taught class, although not significantly so. As the distribution of class sessions for the team taught course followed alternate classes by the three participant instructors for part of the course, the result may indicate how alternate presentations by different instructors resulted in the experience of a less organised, more fragmented course structure.

Questions 5 asked of the instructor(s) effective use of examples and illustrations (Table 5). Again, the non-team taught student mean response was more positive ($M = 4.2$, $SD = .73$), compared to the team taught sample ($M = 3.9$, $SD = .82$). However, this results was again not found to be significant [$t(142) = 1.716, p > .05$]. Survey questions 6, 7 and 8 showed the same pattern of response. The non-team taught student mean indicated more positive responses when asked of the instructor(s) ability to stimulate interest (question 6, $M = 4.0$, $SD = .76$), the instructor(s) knowledge of course content (question 7, $M = 4.3$, $SD = .70$) and the instructors' respect for students (question 8, $M = 4.0$, $SD = .82$), although none of these increased scores in the non-team taught course proved significant (Table 5). In contrast, when asked of the instructors encouragement for student participant (Table 5, Q9), non-team taught student response ($M = 4.2$, $SD = .74$) was found to be significantly more positive than for the team taught students [$M = 3.9$, $SD = .86$, $t(142) = 2.494$, $p < .05$].

Figure 1 illustrates differences in mean response for S1 question nine through box-plots of responses between non-team and team taught students.

As illustrated in Fig. 1, apart from a single outlier, non-team taught responses were more positive in the lowest quartile, compared to the team taught students. There was also more variability in the lowest 25 % of scores in the team taught respondents compared to the non-team taught students. The interquartile range was also greater in the team taught responses compared to the non-team taught students. Finally, 50 % of the non-team taught responses were all above the median score. This was in contrast to the team taught student interquartile range, which also fell below the median score. The team taught students appeared to experience significantly less encouragement to participate then those who were taught by the same instructor individually.

Table 5 S1 (survey 1), section two, questions 4–9

	Condition mean		*t* value	Sig.(2-tailed)
	Team	Non-team		
Q4. Organised presentations	3.9	4.1	1.962	.052
Q5. Good examples	3.9	4.2	1.716	.088
Q6. Stimulates interest	3.9	4.0	.905	.367
Q7. Knowledge of topic	4.1	4.3	1.848	.236
Q8. Respect for students	3.9	4.0	1.062	.290
Q9. Encourage participate	3.9	4.2	2.494	.014

These results indicated the students' experience of the instructor(s) teaching performance (as measured through S1, questions 4–9) was more positive for the non-team taught students compared to the team taught cohort. However, the higher mean scores for all but one of the six teaching performance indicators were shown not to be significant. This result suggested marginal differences in student experiences of instructor(s) teaching performance between the team and non-team taught courses. However, although marginal, these findings indicated a trend towards a more positive experience of teaching performance when classes were delivered by the single instructor, compared to students who experienced team teaching; as indicated in positive mean responses across the six teaching performance questions.

Table 6 illustrates results for S1's third section related to student learning experience (Q10–Q15).

As with S1 section two, section three (Table 6) results indicated a pattern of more positive mean response in the non-team taught course condition compared to the team taught class across the five survey questions (Q10–Q15). For question 10 (assignment opportunities for further learning) non-team taught mean response ($M = 4.0$, $SD = .85$) was higher than the team taught mean ($M = 3.8$, $SD = .99$), although this was not statistically significant [$t(142) = 1.713$, $p > .05$]. Likewise, the amount of assignment work (Q11) received a higher mean response from the non-team taught cohort ($M = 3.7$, $SD = .94$) compared to the team taught respondents ($M = 3.6$, $SD = .95$), although this was again not found to be significant [$t(142) = .885$, $p > .05$]. For question 12, instructor(s) provided helpful feedback on assignments, non-team taught student response was again more positive ($M = 4.1$, $SD = .82$) compared to students experiencing the team taught class ($M = 3.8$, $SD = .98$). Again, however, this result was not significant [$t(142) = 1.749$, $p > .05$]. Question 13 asked of the role and use of technology in improving the learning experience. The non-team taught student group were more positive in their response ($M = 4.0$, $SD = .75$) compared to the team taught group ($M = 3.7$,

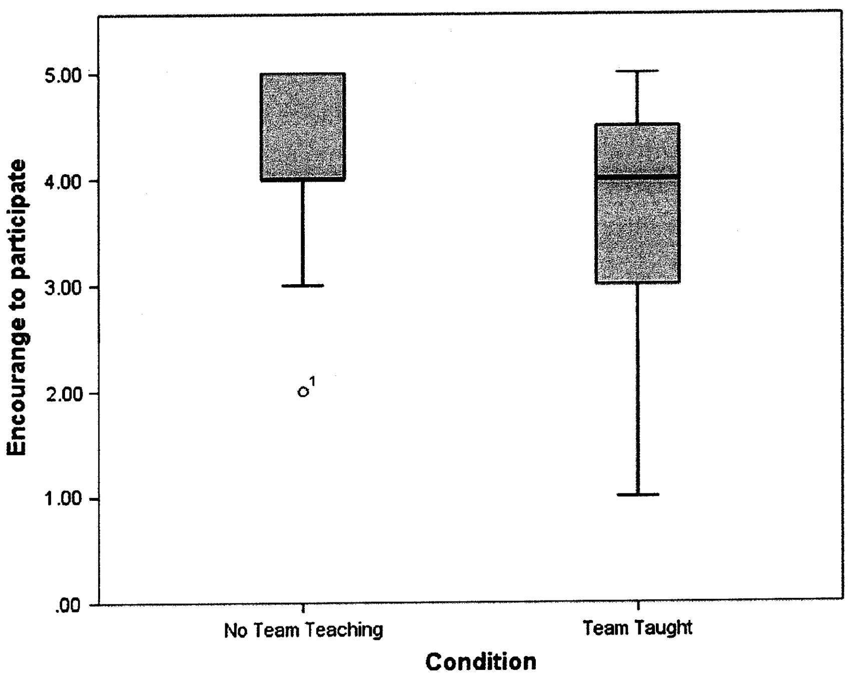

Fig. 1 S1 (survey 1) question nine, the instructor(s) encouraged student participation

Table 6 S1 (survey 1), section three, questions 10–15

Questions	Condition mean		*t* value	Sig.(2-tailed)
	Team	Non-team		
Q10. Assignments and learning	3.8	4.0	1.713	.089
Q11. Homework reasonable	3.6	3.7	.885	.378
Q12. Helpful assignment feedback	3.8	4.1	1.749	.082
Q13. Use of learning technology	3.7	4.0	2.111	.037
Q14. Appropriate difficulty level	3.8	4.0	1.810	.072
Q15. Exams accurately assessed	3.6	3.9	2.334	.021

$SD = .90$), and this result was found to be statistically significant [$t(142) = 2.111$, $p < .05$]. Figure 2 provides the result of S1, question 13 as box-plots.

As shown in Fig. 2, the range of response to question 13 was greater in the non-team teaching condition compared to the team taught class. However, the interquartile response scores for the non-team taught student group ranged above the median line. In contrast, the interquartile team taught responses ranged below the median with two further outliers. As illustrated in Fig. 2, it appears the instructor's use of technology to facilitate learning was significantly more positively experienced in the non-team taught condition compared to team teaching. As the same instructor used the same technology in similar ways across both courses, this was an interesting result. It suggests the students' experience of the instructor(s) utilisation of technology for the benefit of learning was significantly more positive when a single instructor taught the course. However, Fig. 2 also illustrates how variation in response was greatest in the non-team teaching class.

Question 14 (appropriate difficulty level) mean responses for the non-team taught course were greater ($M = 4.0$, $SD = .82$) compared to team teaching ($M = 3.8$,

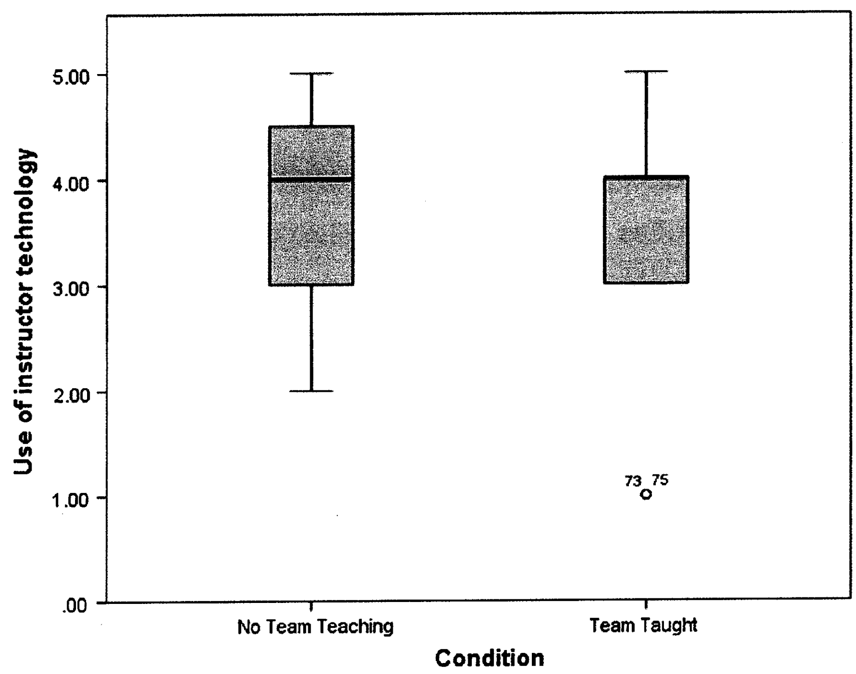

Fig. 2 S1(survey 1) question 13, the instructor(s) use of learning technologies

SD = .83), although not significantly so [$t(142) = 1.810, p > .05$]. Finally, survey question 15 asked if exams and assessments accurately reflected learning during the course. Again, recorded responses from the non-team taught group ($M = 3.9$, $SD = .88$) were more positive than the team taught student response ($M = 3.6$, $SD = .90$). The higher non-team taught scores were also shown to be significant [$t(142) = 2.334, p > .05$], suggesting team teaching significantly influenced the students' experience of the accuracy of exams and assessments. With the non-team taught student cohort recording significantly more positive responses towards the accuracy of exams compared to the team taught class.

As with results across the three sections of S1, team teaching appeared to have a negative influence upon mean response, although differences between the team and non-team taught course were often marginal. However, for three of the 15 S1 questions (Q9 encourage participation, Q13 use of instructor technology, Q15 exams accurately assessed learning) differences in response were found to be significant. These findings are interesting in that they indicated the team teaching approach had a negative impact upon elements of the students' course experience, compared to the non-team taught course. This despite the fact the same instructor was involved in both team and non-team taught courses in successive cycles of the Design Thinking course.

Results S2 (survey 2)

S2 (Survey 2) was designed to focus upon how the team teaching approach influenced the students' experience of interdisciplinary learning and education. Table 7 shows results of an independent means *t* test to examine questions one and two of S2.

S2 question 1 asked if the Design Thinking course provided a clear introduction to ID (industrial design), HF (human factors/ergonomics) and ED (engineering design). Results of independent means *t* tests (*2-tailed*) showed identical mean response between the team taught (M = 4.1, $SD = .68$) and non-team taught classes ($M = 4.1$, $SD = 70$). This result indicated team teaching had no influence upon the students' experience of how the three disciplines were introduced. S2 question 2 asked respondents of their learning experience as it related to the roles of ID, HF and ED in the new product development process. Results showed response to understanding the role of the three disciplines was more positive for those students who took the non-team taught course ($M = 4.2$, $SD = .61$) compared to team teaching ($M = 4.1$, $SD = .75$), although this result was not significant [$t(78) = .328$, $p > .05$]. Surprisingly, however, the non-team taught students learning experience of interdisciplinary roles within a process of new product development was marginally more positive than the team taught class.

The following three survey questions of S2 (Table 8, questions 3–5) asked respondents if they would recommend the course to an undergraduate design student (Q3), a human

Table 7 S2 (survey 2) section one, questions 1 and 2

	Condition mean		*t* value	Sig.(2-tailed)
	Team	Non-Team		
1. Offered clear intros. to design and engineering	4.1	4.1	−.163	.871
2. Understand roles of ID, ED and HF in NPD	4.1	4.2	.983	.328

ID industrial design, *ED* engineering design, *HF* human factors, *NPD* new product development factors student (Q4) and an engineering student (Q5). In order to examine significant differences in the frequency with which respondents provided a 'yes' or 'no' response to questions 3–5, a Chi square test was run with a significance of $p < .05$.

No significant association was found between the type of class experienced by the students (team taught or non-team taught) and whether or not students would recommend the class to a design, human factors or engineering student [$\chi^2(1)$ .213, p .05; $\chi^2(1)$ .409, p .05; $\chi^2(1)$ .952, p .05]. This appears to indicate, based on the odds ratio, the odds of students recommending the course to other ID, HF or DE students was not significantly influenced by the teaching condition. The team teaching approach had no significant influence upon the students' recommendation of the course to their peers.

Questions 6–9 of S2 asked students of their experience of the Design Thinking course in terms of the integration of the three disciplines (Table 9). Again, in order to examine significant differences in the frequency with which respondents provided a 'yes' or 'no' response to questions 6–9 between the two teaching conditions, a Chi square test was run with a significance value of $p < .05$.

Question 6 asked of the course's ability to teach how ID, ED and HF may effectively work together in the design development process. There was no significant association found between the type of teaching (team or non-team) and the respondent's frequency of 'yes' or 'no' response [$\chi^2(1)$ 1.250, p .05]. This suggests the experience of team teaching did not have a significant influence upon their understanding of how ID, ED and HF may work together during design development. However, when asked of the course's equal weighting between ID, ED and HF, a significant association was found between the type of course experienced (team and non-team taught) and the frequency of yes/no response [$\chi^2(1)$ 4.267, p .05]. Figure 3 further illustrates this result, with the horizontal axis showing teaching condition and the vertical illustrating absolute frequencies of response (f).

As shown in Fig. 3, significant differences were identified in the frequency of 'yes' and 'no' response between the two teaching conditions. The frequency with which students responded with 'no' (Fig. 3, blue bars) when asked of the courses' equal weighting between ID, HF and ED was significantly greater in the non-team teaching condition compared to team teaching. Likewise, the frequency with which a 'yes' response was recorded as greater in the team taught condition compared to the non-team taught course (Fig. 3, green bars). These significant differences indicated the team taught students' course provided a learning experience more equally weighted between the three disciplines of ID, HF and ED. That is, the team teaching approach provided students with an interdisciplinary learning experience that was more effectively balanced between the three disciplines compared to the non-team taught class.

Question 8 asked students of the course's ability to provide understanding of the role of design and how it related to engineering and human factors in design thinking (Table 9). A significant association was found between the type of course experienced (team or non-

Table 8 S2 (survey 2), questions 3–5

Questions	Team (count)		Non-team (count)		Value	Sig.(2-sided)
	Yes	No	Yes	No		
3. Recommend to design student?	37	3	38	2	.213	.644
4. Recommend to human factors student?	35	5	38	2	1.409	.235
5. Recommend to engineering student?	30	10	26	14	.952	.329

Table 9 S2, section one, survey questions 6–9

Questions	Team (count)		Non-team (count)		Value	Sig.(2-sided)
	Yes	No	Yes	No		
6. Taught how ID, ED, HF work together	34	6	30	10	1.250	.264
7. Equaly weighted between ID, ED and HF	14	26	6	34	4.267	.039
8. Understand design as related to ED and HF in DT	32	8	22	18	5.698	.017
9. Course helpful to other studies at the [a]DHE?	26	14	34	6	4.267	.039

ID industrial design, *ED* engineering design, *HF* human factors

[a] School of Design and Human Engineering, UNIST

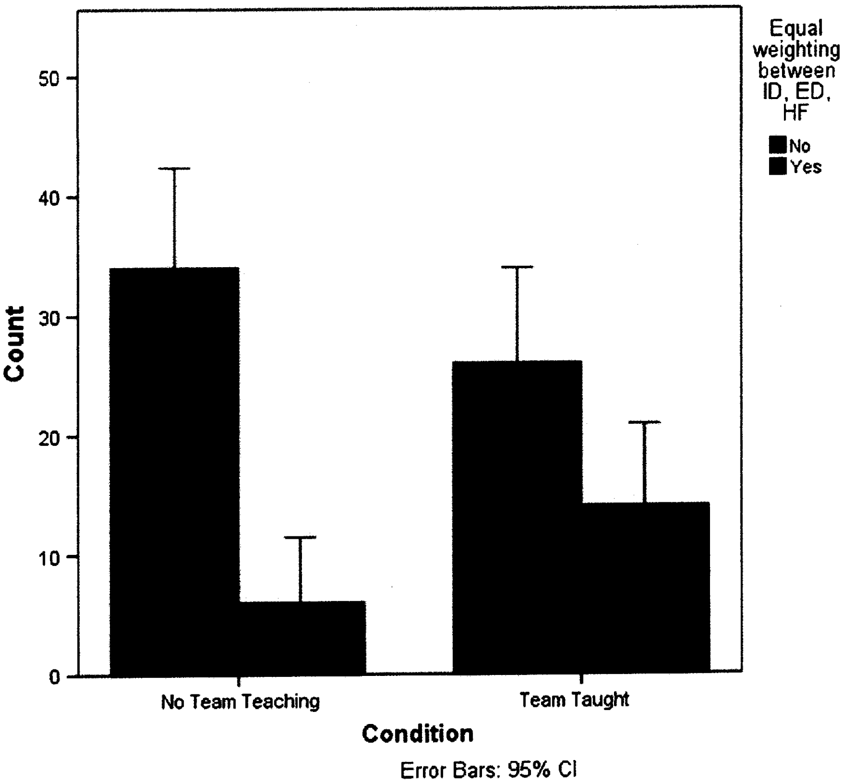

Fig. 3 S2 question 7, the course was equally weighted between ID, Ed and HF

team taught) and the frequency of yes/no response [$\chi^2(1)$ 5.698, p .05]. Figure 4 further illustrates this result.

As shown in Fig. 4, students experiencing the team taught course responded significantly more often with a 'yes' response compared to those taking the non-team taught course (Fig. 4, green bars). In contrast, the non-team taught students registered a 'no' response significantly more often when asked of the course's ability to provide understanding of how ID, ED and HF related to design thinking (Fig. 4, blue bars). These results indicated an understanding of how the three disciplines related to the course topic was more strongly felt in the learning experience of the team taught students compared to those taught by a single instructor. That is, the team teaching approach was significantly more effective in providing students with greater opportunities to learn and understand how ID, HF and ED related to Design Thinking. In contrast results indicate the non-team taught course was significantly less effective in providing opportunities for students to better understand the role the three disciplines play in design thinking during new product development.

Question 9 asked if the respondents felt the course may be of value to students from other majors from across the respondents' institution. Again, a significant association was found between the type of course experienced and the frequency of yes/no response to the question of course relevance for other majors [$\chi^2(1)$ 4.267, p .05] (Fig. 5).

As shown in Fig. 5, students experiencing the non-team taught course responded 'yes' significantly more often when asked if they would recommend the course to others across the institution compared to the students who had experienced the team taught course (Fig. 5, green bars). Likewise, the team taught students also responded 'no' more often than the non-team taught respondents (Fig. 5, blue bars). This result indicated the experience of being team taught had a negative effect upon the students' willingness to recommend the course to other students from different schools and majors across their institution. In contrast, students who had experienced the course with the single instructor appeared more inclined to recommend the course to others. This again was an interesting result as it suggested the team teaching approach had a negative influence upon the students' willingness to recommend the Design Thinking course to other majors, thus suggesting the students' experience of team teaching was less positive than when taught by the single instructor.

Discussion and conclusion

The current study has explored team teaching as strategic approach to interdisciplinary education in the field of design at undergraduate level at the School of Design and Human Engineering (DHE), UNIST (Ulsan National Institute of Science and Technology). For this

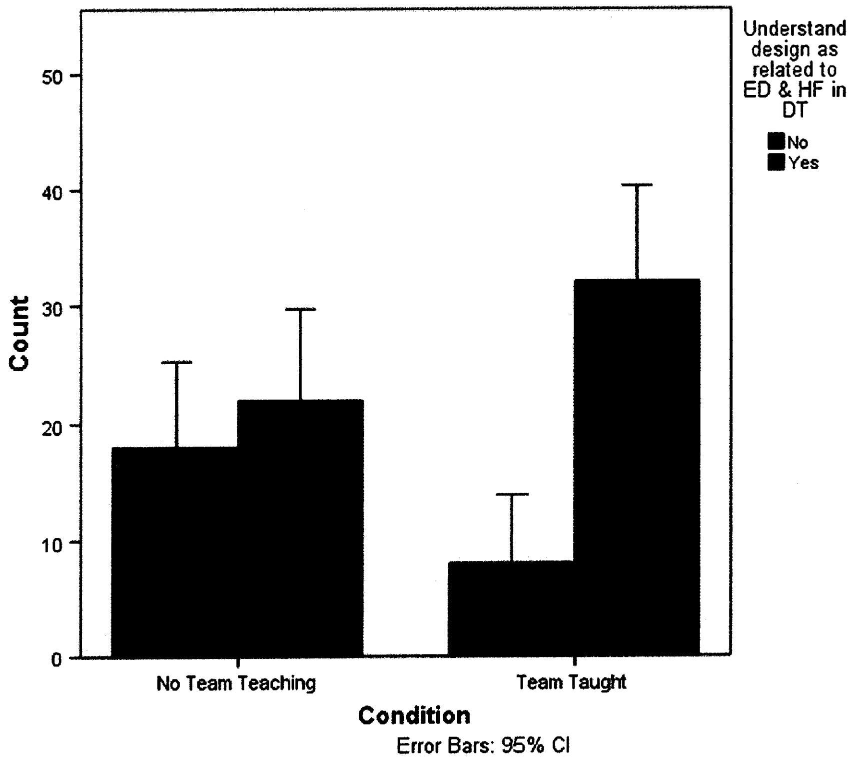

Fig. 4 S2 question 8, ability to provide understanding of the role of design as related to engineering and human factors in design thinking

research purpose a comparative analysis of team and non-team teaching was conducted to examine the influence of team teaching upon student learning experience. To achieve this, two surveys (S1 and S2) were deployed in two cycles of the same Design Thinking course, with students from both team and non-team taught cycles responding to questions on their holistic learning experience (S1) and learning experience as related to their experience of interdisciplinarity (S2). Survey findings were subjected to a comparative, statistical analysis.

Results from the study's first survey (S1) indicated how the sample of non-team taught students provided a more positive overall opinion of course quality, although these differences were not found to be statistically significant. This result indicated team teaching as an approach to interdisciplinary design education did not significantly benefit holistic learning experiences. It is unclear as why this may be. One reason may have been the students' lack of grounding in any one discipline. As second year undergraduate students their inability to benefit from the approach may have been the result of a limited experience of any single discipline of study. This would agree with the notion of an Awareness of Disciplinarity as important to the success of interdisciplinary pedagogic strategies (Lattuca et al. 2013; Mansilla and Gardner 2003). For students to benefit from interdisciplinary approaches a certain level of disciplinary knowledge may be required to effectively synthesise knowledge, methods and ideas from adjacent disciplines. As such, an interesting direction for future study would be the exploration of the relationship between different levels of disciplinary knowledge (i.e. year groups), the use of team teaching in design as strategy for interdisciplinarity and implications for effective knowledge integration.

A further finding from responses to S1 showed students experienced significantly less encouragement to participate when team taught compared to when taught by the single

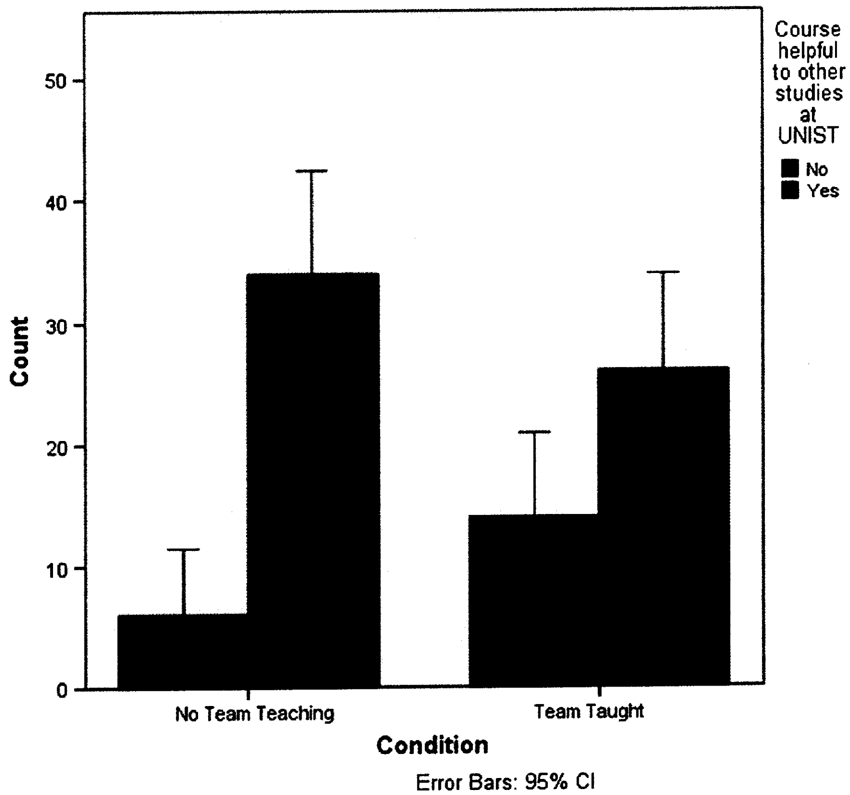

Fig. 5 S2 question 9, the design thinking course is helpful to other majors

instructor. Team teaching thus appeared to have a negative impact upon the students' experience of instructor encouragement. This may point to the influence of the instructor's contribution as important in providing opportunities for students to feel encouraged to participate. This would then agree with Lee (2014), who emphasises the importance of increased effort in the facilitation of interdisciplinary learning. That is, to leverage team teaching as an approach to interdisciplinary education requires a more substantive investment in time and planning compared to a conventional single instructor approach. Thus, while all three instructors had substantive skill and experience within their respective fields of expertise, they may have been less able to reach across disciplines in their application of knowledge in pursuit of student learning needs. Without understanding both a requirement for greater effort in planning and time and increased interdisciplinary understanding in teaching across disciplinary boundaries, greater potential exists for negative consequences in terms of student learning. On the other hand, investment in both time and planning and care in execution of an interdisciplinary approach, has the potential to provide undergraduate design students with a richer understanding of adjacent disciplines compared to course planning and delivery through a single instructor.

In the study's second survey (S2) significant differences in student response were identified when asked of the equal weighting between the three disciplines present within the design thinking course: industrial design, human factors and engineering design. Results showed how student learning through team teaching significantly increased the students' experience of a balanced contribution of knowledge from across the three disciplines compared to students' taught by the single instructor. These findings agree with those of Oehlberg et al. (2012), who highlight how an interdisciplinary approach provided opportunities for students to broaden their own learning experience, acquiring an increased breadth of knowledge and experiences. Results thus indicate the potential of team teaching to provide opportunities for students to more successfully experience equally distributed learning, reflective of the disciplines present within the team of instructors. As such, findings provide evidence to suggest how the strategic use of team teaching provides design pedagogy opportunities for balanced learning experiences that cut across disciplinary boundaries. Further work is required to examine, for example, how the team teaching approach is able to facilitate interdisciplinary learning experiences so as to leverage the strategic use of team teaching in pursuit of a more balanced approach to student learning and knowledge acquisition.

Results also showed how understanding of the disciplines represented within the course (industrial design, human factors, systems engineering) related to the course topic (Design Thinking) differed between the team and non-team taught student cohorts. Findings showed the team teaching approach to be significantly more effective in providing students with greater opportunities to understand how industrial design, human factors and engineering design related to Design Thinking. From these results it appears the team taught students experienced a course that more successfully provided opportunities to consider how the three disciplines contributed to the overarching course subject: Design Thinking. Although the current study does less to identify the reasons for the team approach's apparent benefit to understanding disciplinary synthesis, it appears the use of team teaching in design can potentiate greater understanding of interdisciplinary roles as they may relate to a given overarching topic or theme.

Finally, results from S2 showed the experience of being team taught had a significant negative effect upon the students' willingness to recommend the course to other students from different schools and majors across the authors' institution. In contrast, students who had experienced the course with the single instructor were significantly more inclined to recommend the course to others compared to the team taught students.

To summarise our findings we return to Oehlberg et al. (2012) key question as means to assess the effectiveness of team teaching as strategy for the facilitation of interdisciplinary learning experiences: Are gains in students' knowledge and skills attributable to the interdisciplinary (team teaching) nature of the course? In our concluding discussion we revisit Klein and Newell (1998) definition of interdisciplinary learning.

> A process of answering a question, solving a problem, or addressing a topic that is too broad or complex to be dealt with adequately by a single discipline or profession...and draws upon disciplinary perspectives and integrates their insights through construction of a more comprehensive perspective.
>
> (Klein and Newell 1998)

As indicated in our empirical findings, although the approach to interdisciplinary learning through team teaching described in this study did draw upon the disciplinary perspectives of industrial design, human factors and engineering design, the integration of interdisciplinary learning appeared less successful from the perspective of the student experience. Although some aspects of interdisciplinary learning did appear to be significantly potentiated through a team teaching approach (i.e. understanding contributions of industrial design, human factors, engineering design; experience of how the disciplines work together to inform Design Thinking), the overall pattern appeared to indicate a more satisfied the student learning experience when the course was conducted by a lone instructor.

Team teaching as approach to provide interdisciplinary skills and opportunities to develop more creatively strategic knowledge appeared to have a limited impact upon student learning experience. A pattern of marginally more positive experiences in the non-team taught condition was also interesting in its suggestion of the limitations of the approach in terms of student experiences. However, generalization of results as they apply to the students' acquisition of interdisciplinary skills and knowledge must be made with caution. First, although the two surveys used in the empirical analysis of responses compared learning experiences between team and non-team teaching approaches in the same course over two academic cycles, results do not examine how the approach influenced knowledge acquisition. Second, other influential factors were not considered in the quantitative analysis of results (i.e. preparation time over the two courses, instructor profiles and experience, student profiles within the two groups).

Rather than providing a set of definitive issues to explain the success or otherwise of the team teaching approach at undergraduate level, we position this study as further evidence to suggest how successful interdisciplinary interventions in design pedagogy require increased effort in terms of both course curricula and effective instruction. We suggest more work is now needed to identify and well explicate the key factors required in the strategic use of team teaching and its successful application in support of interdisciplinary learning experiences. For example, how instructor interaction and collaboration in the preparation and execution of team taught design courses may influence student learning experiences. We also recommend the further examination of interdisciplinary design courses as they are conducted in the classroom and studio context to identify the drivers and barriers to interdisciplinary knowledge, skills acquisition and implications for learning experiences.

As design, by nature, is a field of disciplinary convergence, there can be no doubt in the potential benefit of interdisciplinary learning in undergraduate design education. Further studies of team teaching as means to facilitate interdisciplinary learning experiences have the potential to provide strategies for more appropriate team teaching methods. This will then benefit design pedagogy through the leveraging of interdisciplinary knowledge in pursuit of effective and engaging interdisciplinary learning experiences, skills and knowledge acquisition.

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References

Adams, R. S., Turns, J., & Atman, C. J. (2003). Educating effective engineering designers: The role of reflective practice. *Design Studies, 24*(3), 275–294.

Affairs, Educational. (2013). *UNIST 2013 course catalog*. In UNIST (Ed.), Ulsan National Institute of Science and Technology (UNIST).

Carulli, M., Bordegoni, M., & Cugini, U. (2013). An intergrated framework to support design & engineering education. *International Journal of Engineering Education, 29*(2), 291–303.

Jaeger, A., Mayrhofer, W., Kuhlang, P., & Matyas, K. (2013). Total immersion: Hands and heads-on training in a learning factory for comprehensive industrial engineering education. *International Journal of Engineering Education, 29*(1), 23–32.

Kang, N. (2008). *Activation plan for the convergence study of scientific technology & humanities and social sciences*. Ministry of education, science and technology.

Kaygan, P. (2014). 'Arty' versus 'Real' work: Gendered relations between industrial designers and engineers in interdisciplinary work settings. *The Design Journal, 17*(1), 73–90. doi:10.2752/175630614X13787503069990.

Kim, K., Kim, N., Jung, S., Kim, D. Y., Kwak, Y., & Kyung, G. (2012). A radically assembled design-engineering education program with a selection and combination of multiple disciplines. *International Journal of Engineering Education, 28*(4), 904–919.

Klein, J., & Newell, W. (1998). Advancing interdisciplinary studies. In W. Newell (Ed.), *Interdisciplinarity: Essays from the literature*. New York: College Entrance Examination Board.

Kolb, D. (2014). *The structure of knowledge experiential learning: Experience as the source of learning and development* (2nd ed., pp. 153–192). New Jersey: Pearson Education Inc.

Lattuca, L. (2001a). *Considering interdisciplinarity creating interdisciplinarity: Interdisciplinary research and teaching among College and University faculty*. New York: Vanderbilt University Press.

Lattuca, L. R. (2001b). *Creating interdisciplinarity: Interdisciplinary research and teaching among college and University faculty*. Nashville: Vanderbilt University Press.

Lattuca, L, & Knight, D. (2010). AC 2010-1537: In the eye of the beholder: Defining and studying interdisciplinarity in engineering education.

Lattuca, L., Knight, D., & Bergom, I. (2013). Developing a measure of interdisciplinary competence. *International Journal of Engineering Education, 29*(3), 726–739.

Lattuca, L. R., Voight, L. J., & Fath, K. Q. (2004). Does interdisciplinarity promote learning? Theoretical support and researchable questions. *Review of Higher Education, 28*(1), 23-C.

Lee, J. (2014). The integrated design process from the facilitator's perspective. *International Journal of Art and Design Education, 33*(1), 141–156. doi:10.1111/j.1476-8070.2014.12000.x.

Mansilla, V., & Duraising, E. (2007). Targeted assessment of students' interdisciplinary work: An empirically grounded framework proposed. *The Journal of Higher Education, 78*(2), 215–237.

Mansilla, V., & Gardner, H. (2003). Assessing interdisciplinary work at the frontier: An empirical exploration of "symptoms of quality". In G. Origgi & C. Heintz (Eds.), *Rethinking interdisciplinarity*. Cambridge: Harvard University.

Mendoza, H. R., Bernasconi, C., & MacDonald, N. M. (2007). Creating new identities in design education. *International Journal of Art and Design Education, 26*(3), 308–313. doi:10.1111/j.1476-8070.2007.00541.x.

Mok, Y. H. (2009). *Korea education in the age of knowledge convergence*. Paper presented at the autumn conference of Korean educational research association.

Newell, W. (2001). A theory of interdisciplinary studies. *Issues in Integrative Studies, 19*, 1–25.

Norman, D. (2010) Why Design Education Must Change. Core77, Retrieved from http://www.core77.com/posts/17993/why-design-education-must-change-17993

Norman, D, & Klemmer, S. (2014). State of design: How design education must change. Retrieved from https://www.linkedin.com/pulse/20140325102438-12181762-state-of-design-how-design-educationmust-change.

Oehlberg, L., Leighton, I., & Agogino, A. (2012). Teaching human-centred design innovation across engineering, humanities and social sciences. *International Journal of Engineering Education, 28*(2), 484–491.

Repko, A. (2012). *Interdisciplinary research: Process and theory* (2nd ed.). New York: SAGE Publications Inc.

Strong, D. (2012). An approach for improving design and innovation skills in engineering education: The multidisciplinary design stream. *International Journal of Engineering Education, 28*(2), 339–348.

Suh, S. G., & Park, S., J. (2009). The Korean Government's Policies and Strategies to Foster World-Class Universities. In Cheng, Y., Wang, Q. & Nian, C., L. (Eds.), *How World-Class Universities Affect Global Higher Education.* (pp. 65–83). Rotterdam: SensePublishes.

The Korean Ministy of Education, Science and Technology. (2008). *World Class University Project.*

Thompson, M. (2009). *Increasing the rigor of freshman design education.* Paper presented at the iasdr09, Seoul. http://www.iasdr2009.or.kr/index.html. Accessed 15 Jan 2015.

Thompson, M. K. (2009). *ED100: Shifting paradigms in design education and student thinking at KAIST.* Paper presented at the CIRP design conference 2009.

Tolbert, D., & Daly, R. (2013). First-year engineering student perceptions of creative opportunities in design. *International Journal of Engineering Education, 29*(4), 879–890.

Yim, H, Lee, K, Brezing, A, Lower, M, & Feldhusen, J. (2011). *Learning from an interdisciplinary and intercultural project-based design course.* Paper presented at the international conference on engineering and product design education, City University, London, UK.