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Collaborative Design Learning and Thinking Style Awareness*

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This paper reports on a concerted attempt to develop the design ability and creativity of students from different engineering disciplines through a Project-Based Learning (PBL) approach in a collaborative educational environment. A heavy reliance was placed on teaching the students six styles of thinking, especially in the beginning and final phases of project design. Different collaborative learning experiences in product design were conducted, which required students to practise six styles of thinking. Using a thinking style inventory, pre- and post-survey, data were collected and successively analysed through ANOVA techniques. Statistically significant results showed that students successfully developed empathy and an openness to multiple perspectives. Furthermore, data analysis confirmed that the proposed collaborative learning experience positively contributed to increased awareness in students' thinking styles.

Keywords: collaborative design learning; thinking style; project-based learning; preferential thinking

1. Introduction

Project-Based Learning (PBL) is an effective way for students to learn design by experiencing design as active participants. It is a form of experiential learning where design projects motivate and integrate learning, and is considered to be a major innovation in design pedagogy [1]. PBL experiences can be used to improve the abilities of student designers to work collaboratively, to develop communication skills and to design thinking—all of which embrace the heart of the design process by highlighting the creation, assessment, selection and realization of ideas [2, 3].

It is acknowledged that students all come from different engineering disciplines and will be characterized by different thinking style profiles. These factors affect their ability to work collaboratively during a PBL experience in an educational environment. Our intention is to reduce negative effects of diversity during collaboration (e.g. misunderstandings, stress and conflict.) while improving positive influences (e.g. enhanced student abilities and group creativity). With this aim, we present a PBL experience approach for collaborative product design learning aimed to enhance students' awareness of their own preferential thinking style. The approach follows the idea that creativity arises through knowledge-sharing and synergies created through having many student designers working with virtual groups and a team coordinated by a teacher who plays the role of concept design manager[1]. Although other scholars have tried to deepen our understanding of the nature of learners' interactions within collaborative learning environments [4], our aim in this paper is to report on preferred thinking style of learners who work and interact during a PBL experience.

The paper is organized as follows. After reviewing the theoretical background in Section 2, a full description of the adopted approach is proposed in Section 3. In Section 4, research questions and survey design are presented. Section 5 reports overall results of a survey on 202 design students, undertaken whilst the students engaged in a PBL experience, whose first results have already been presented previously [5, 6]. Statistical analyses confirm that PBL experiences increase the overall diversity of students' self-reported thinking style preferences. Such variation is found to be in contrast with much of the thinking style literature where

[1] According to [10], we define a *group* as a 'collection of individuals whose contributions to a product or a process are additive and can be collated and presented by a group manager as the result of group effort. Performance evaluation and accountability for a group will occur at the individual rather than the collective level'; we define a *team* as a 'collection of individuals who interact more extensively than group members to produce a deliverable, who are evaluated based on the team outcome, and who are accountable as a team (instead of or in addition to individual accountability) for team outcomes'; we define a *virtual group* (or *virtual team*) as a group (respectively, team) whose members are geographically, temporally, and/or organizationally dispersed and brought together across time and space by way of information and communication technologies to accomplish an organizational task.

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styles are thought to be relatively fixed and difficult to change. To test our hunches about the improved empathy displayed by students after such a PBL experience, a further pilot was conducted on a new sample of fourteen design students. Such test particularly concerns the internal consistency of CD-TSI and students' thinking style awareness; statistical results and discussion are also reported in Section 5. Finally, Section 6 presents the conclusions and future areas of study.

2. Theoretical background

Design problems are understood from different perspectives, thus a collection of differently skilled designers can, in principle, go beyond individual knowledge and reach new concept ideas [8, 9]. For this reason, manufacturing companies often embrace collaborative approaches in product design processes by involving experts from different disciplines in sharing knowledge, performing the design tasks and organizing resources. This approach assumes relevance and importance in the early stages of the product design process (otherwise known as the concept design phase[2]) where intensive collaboration among designers is necessary to create a shared understanding of the product concept. This then creates a formal description of the form, function and features of the product [5].

Many researchers affirm that thinking style diversity among individuals involved in a collaborative work will be fundamentally responsible for tension leading to conflict. However this can also provide the most effective creative solutions [10, 11]. From an educational perspective, one problem is to establish if and how experiential collaborative learning might affect thinking style preferences and thus create greater diversity among student designers' ways of thinking about design issues.

Design is both a practice and a way of thinking, so experiential design in education gives an opportunity to engage learners and explicitly guide their intellectual process. When student designers work collaboratively, not only do they learn technical content but they also develop intellectually in order to communicate their creative ideas and collaboratively apply that content in meaningful ways [12].

The attention to style of thinking comes from a keenness to optimize human use of intellectual and creative abilities within many work and life contexts. Over time, an increasing number of researchers have turned their attention to the issue of investigating the relationship between preferential thinking style and professional life. For instance, [13] reported an interesting study regarding detectives' investigative thinking styles. Adaptability leads to enhanced success so that optimizing performance may result from matching thinking style to the environment. Research findings on thinking styles provide a deeper understanding of the different ways in which people focus to make sense and use of the world. Different variables can have a coercive effect on one's style of thinking including one's family and workplace [14]. The result of this is that people may choose to live and work in contexts that suit their style of thinking [15, 16]. From the literature it is reasonable to conclude that thinking style impacts on performance.

Designers' creativity and diversity play a crucial role in collaborative processes. This is readily apparent when one considers that most creative pursuits in industry involve many individuals with various competencies working together to develop a product concept that cannot be created by a single individual alone [17]. Using creativity therefore leverages the intelligence of different designers to tackle the complexity and uncertainty of generating a product concept. Many studies have looked at the issue of diversity as playing a key role in the collaborative development of a new product concept. Types of diversity frequently studied relate to gender, ethnicity, years of experience, technical discipline, Myers-Briggs type, and communication media [18–20], but very few studies have specifically regarded thinking style diversity between designers engaged in product concept generation.

Thinking style bridges many domains including cognitive, affective, psychomotor, physiological, psychological and sociological realms. Style of thinking is first and foremost both cognitive and affective in essence. It is cognitive because information is processed; it is affective because one's feelings are involved in one's preferred way of thinking such as welcoming or avoiding various aspects such as authority, conformity, structure, ambiguity, reflectivity and impulsivity. In a more integral sense, style of thinking is 'affective' first and foremost since it refers to preferred thought processes, to the most comfortable ways of thinking. Thinking style has psychomotor and physiological dimensions because one's nervous system and senses are involved in how information is preferred to be perceived and pro-

[2] In the literature [17] and [3] a *product concept* is defined as a description of the form, function and features of the product and is usually accompanied by a set of specifications, an analysis of competitive products, and an economic justification of the project; *concept development* is defined as the first phase in the product development process where the needs of the target market are identified, alternative product concepts are generated, and a single concept is selected for further development; *concept design* is defined as the work done (task clarification, hypothesis formulation, solution searching), on a product concept by designers in the concept development phase in order to determine a product concept architecture.

cessed. It is psychological because the choice includes preferential interaction of one's personality with the context. To the extent that the context is social, then style is also sociological because it is contingent on preferred crossing points with others. It is therefore evident that style of thinking is a social whole-person preference involving more than the brain alone but also one's creative sense of intuition and feeling. Style of thinking is independent of intelligence and there is some unexplained variation in the theory of intelligence [15]. Style and ability may be confused at times as people may be thought to be incompetent because of lack of ability, where in reality it is an inappropriate use of their ability in their preference for the way of thinking.

Only a portion of performance is attributed to intelligence, the rest is due to one's preferences for thinking and dealing with information and situations. Contemporary theories of thinking styles have been suggested to explain some of the variation. The theory of reality construction is a general theory that under-emphasizes the principles of societal or mental self-government [15] and focuses on dimensions of dependence, inquiry, multiple perspectives, autonomy and imagery [21]. The Thinking Styles Inventory (TSI) emanates from a theory of how people create their reality through their thinking and measures reported preferences for stylistic aspects of intellectual functioning. Inventories based on interviews have been used for comparative analysis in the fields of adult education, cognitive functioning and learning styles for a long time [22]. The name of the theory of reality construction emanates from constructivist theory, the idea that people actively construct their reality from their social interactions, which are based on personally preferred ways of thinking. Interpersonal responses or interactions are based on how people like to think about problems. Sofo's theory of reality construction is a meta-cognitive perspective that underpins five styles of thinking [21]. Some of these styles (Exploring, Independent and Creative) may be referred to as divergent thinking, reflecting Zhang's [22] category 1 thinking (Creative), while the Conditional and Inquiring categories are examples of convergent thinking and are similar to Zhang's category 2, concrete thinking. The styles also fit nicely into Zhang and Sternberg's [23] intellectual styles model. The fives styles refer to how a person likes to accept, make sense of, and react to information, people and tasks. The theory maintains that there are at least five mental styles (see Table 1) used in combination as a profile of styles in social interaction and in problem solving within different contexts. The relative response scores on each of the five styles produce a thinking style profile relevant to the particular individual.

Table 1. Summary of the five thinking styles on the TSI [24]

1. Conditional	Accepting what others think and say without questioning them.
2. Inquiring	Asking questions to improve understanding of message or information.
3. Exploring	Looking for alternatives and difference.
4. Independent	Allocating priority to one's own thinking.
5. Creative	Thinking in pictures to get a sense of the whole.

A person with a particular preference in one circumstance may have a different inclination in another situation, which means that people may be flexible and adaptive in their thinking. This also suggests that style of thinking is at least partly socialized because the environment can influence the style that a person prefers to use [15]. It follows that the key assumption relevant in the development of the measurement of Sofo's theory is that people can be located within a blend of thinking preferences, ranging from conditional to creator, dependent on the characteristic mode in which they solve problems, and create or make decisions. All thinking styles are potentially useful. The challenge is to use a style that works best for a person in each situation. A situation is dominated by the demands placed there by outside influences such as the law, social expectation, issues of safety and expediency. Other influences may include the demands of a profession, how those in charge of a situation expect subordinates to behave and pressures that individuals may impose on themselves.

De Bono's [25] six coloured hats method is a critical thinking method of organizing thinking patterns so that a person who is thinking can adopt a specific thinking style at any time, instead of having to try to combine all thinking styles at once. Multicolour printing is a useful analogy to explain these six thinking styles. Each colour is printed in a separate step and in the final step all the colours are combined. By analogy every person has the capacity for critical thinking by combining the expert use of all six styles of thinking; [26] used this method to design product concepts, reporting a comparative study on the results of a competitive design project simultaneously undertaken by two multidisciplinary new product development teams.

3. The PBL approach

Following the constructivist approach, an educational environment is a (virtual and physical) microworld where students and teachers meet to work together, interacting with each other, using a variety of tools and sources of information that allow them to look for learning objectives and activities in order to solve problems. The design of such an educational environment constructed on resource-based models has long been debated [33]. Studies have shown that the setting-up of an educational environment within a classroom of student designers is the prerequisite for conducting a PBL experience [2, 27].

The educational environment should comprise at least four components [6]:

1. *Information sources*: Online and offline learning materials (books, encyclopaedias, teachers' notes, digital libraries, etc.), lab software reference guides, people analysis documents.
2. *Technological infrastructure*: An integrated set of Web 2.0 tools that enable educational modalities, such as manipulating and constructing symbols, accessing and searching for information, asynchronous and synchronous interacting with students and teachers, delivering immediate feedback and reports of student or team performance to the teacher. According to [28], such tools give individuals the opportunity to participate in a collective development of knowledge and, at the same time, benefit from the vast amount of knowledge that is available worldwide.
3. *Simulation*: The implementation of a model of real situations by creating a learning context that drives the student to analyse, integrate, synthesize and apply basic knowledge for solving problems.
4. *Strategy*: A structured set of pedagogical activities that serves as a guide, a feedback source and promotes collaborative learning. A review of educational literature indicates that academic organizations' learning strategies are shifting towards a more active and group-oriented learning, referred to as cooperative or collaborative learning [25].

For conducting a PBL experience, the following roles are taken into consideration in the educational environment:

- Concept Design Manager (CDM), played by the teacher;
- Creative Designer Group (CDG), made up of some students in the classroom;
- Evaluation Designer Team (EDT), made up of all the students in the classroom.

Members of the CDGs, who may be geographically dispersed, are required to work independently on the creative problem solving task. To better carry out their tasks, student designers can use the available ICT tools and information sources. Members of the EDT interact face to face and work together in collaborative sessions to evaluate ideas/solutions developed by CDG members.

To better manage and control activities and student performance within the educational environment it should be restricted to twenty students interacting at a time.

The PBL experience comprises a cascade of four stage-gates consisting of defining concept visions, functional schema, functional layouts and construction solutions for a digital mock-up of an innovative product (e.g. a device).

1. The first stage generates product concept visions (CVs) in response to a request forwarded by the CDM to the student designers.
2. The second stage receives CVs as input and generate functional schema FSs related to each of them. The purpose of a functional scheme is to define the functional structure of the product, i.e. macro system components and their interactions.
3. The third stage receives FSs as input and gives out functional layouts (FLs) each of which specifies the preliminary layout, i.e. mutual position of each subsystem and their possible volumes, and principle solutions for each subsystem.
4. The fourth stage generates some constructive solutions (CSs) with respect to selected FLs.

A graphical representation in IDEF0 notation[3] of the four stage-gates constituting the PBL experience process is shown in Fig. 1.

Each stage is composed of five sequential steps developed as follows (see Table 2). In Step 1, one or more requests for proposal (ideas or solutions) are transmitted by the CDM to the classroom. Each request contains the specification of the concept vision (for the first stage) or of one of the successful proposals selected by the CDM as output of the previous stage (for stages after the first).

In Step 2, 'generating ideas/solutions' the requests are received by way of input; for each of them a CDG can be formed; thus each CDG consists of the student designers who autonomously choose to work independently on the same request for proposal. The output of this step is the set of original ideas/solutions that can be submitted by each student designer to the CDM. In forming a CDG, teachers neither define the group composition nor select a known leader. This is for two main reasons: first, many students do not possess the experience and skills required to be part of a successful team/group; second, as engineering edu-

[3] The IDEF0 functional modelling method is designed to model the decisions, actions and activities of an organization or system [29].

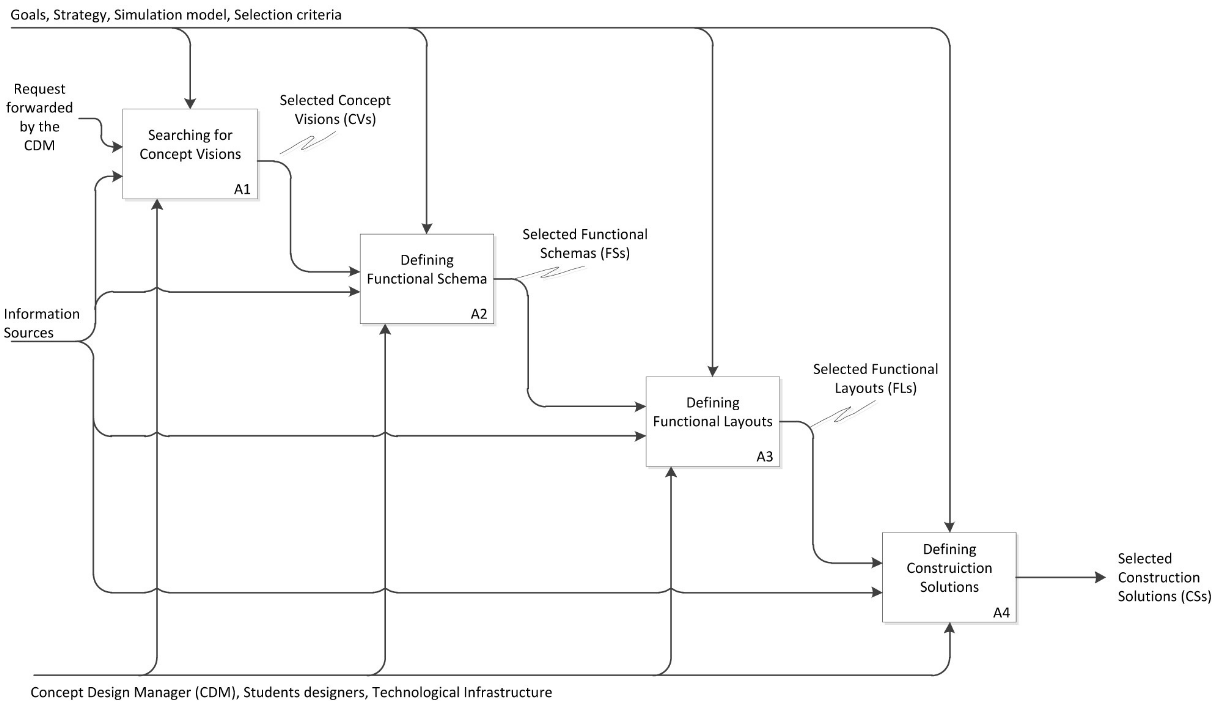

Fig. 1. Graphical representation of the process in IDEF0 notation.

Table 2. Steps and roles in each stage

Steps in each stage	Roles
1. Launching call for proposals	CDM
2. Generating ideas/solutions	Each designer in a CDG
3. Collecting ideas/solutions	CDM
4. Evaluating ideas/solutions	Designers in the EDT
5. Ranking and selecting ideas/ solutions	CDM

cators, we are committed to furthering the educational growth of all our students in our course, not just the few talented ones who already possess the skills to succeed. Generating ideas and solutions is a divergent thinking activity aimed to stimulate the creativity of independent student designers in order to obtain a larger number of innovative proposals. Such proposals are thus collected by the CDM during Step 3 'Collecting ideas/solutions' and are assessed in a collaborative session, 'evaluating ideas/solutions', by the EDT. To stimulate convergent thinking during this session, the EDT evaluates proposals collected by the CDM using De Bono's (1990) six thinking hats method and submits such evaluations to the CDM. During Step 5, 'ranking and selecting ideas/solutions', the CDM, on the basis of the evaluations of the previous step, ranks the proposals and selects those most suitable for successive development (the next stages) or for final teacher–student evaluation.

Each evaluation step consists of a collaboration session performed by the EDTs and is based on De Bono's 'six coloured hats' method. Such a method has been already used to design product concept by [26], who reported a comparative study on the results of a competitive design project undertaken simultaneously by two multidisciplinary new product development teams. In the application of this method we consider six 'coloured' sub-sessions. During each session all members of the EDT metaphorically wear a hat of the same colour of the sub-session. These hats indicate the type of thinking being used by EDT's members and the type of contribution they are required to give, (see Table 3).

4. The survey design

The two research questions for this study are:

1. Can a PBL experience affect the diversity of student self-reported thinking style preferences?
2. Can the student's involvement in some design situations induce a variation in components of their self-reported thinking style preferences?

In order to answer these questions, we conducted a research survey on a sample of 202 student designers attending blending learning classrooms. Such a sample was surveyed using a version of the Thinking Style Inventory [3] specifically tailored to collaborative product design learning, the Concept Design—Thinking Style Inventory (CD-TSI). The purpose of conducting the survey was to analyse the self-report

Table 3. A framework for critical thinking in collaborative evaluation sessions

Colour	Type of thinking	Type of contribution
White	Impartial and objective; neither interpretations nor opinions are taken into account; search for information related to the proposed ideas/ solutions.	Data requests and precise questions in order to obtain new information or supplement incomplete information.
Yellow	Positive and constructive; search for benefits, values and reasons to be optimistic about the proposed ideas/solutions.	Positive assessments that cover a spectrum ranging from the logical and practical at one end to dreams, visions and hopes at the other end.
Black	As devil's advocate to see why something won't work; search for faults, problems, risk and dangers related to the proposed ideas/ solutions.	Negative assessments that point out what is wrong, incorrect or defective and ways in which something is contrary to experience or established knowledge.
Red	Awareness of hunches, premonitions and intuitions about the proposed ideas/solutions. Feeling and emotions are legitimized as essential components of thinking.	Expressions of feelings so that they can be integrated in the thought map and also made part of the evaluation system that selects the route on the map.
Green	Creative, lateral and fertile in order to see beyond the familiar, the obvious and the 'good enough'.	Creative statements and sowing seeds for alternative ideas or solutions.
Blue	Cool and controlled; thinking about thinking that is necessary for the evaluation of ideas/ solutions.	Organization and summarization of outputs of other coloured sub-sessions. Requests for opening another coloured sub-session with the definition of the objects to which thinking is to be applied and the thinking tasks to be performed.

of student designers with regard to changes in their thinking style preferences following the PBL experiences. To do so, pre-delivery and post-delivery data were collected and reported for each student attending.

4.1 The sampled classrooms

Three PBL experiences were designed according to the proposed PBL approach; each experience consisted of selected activities developed over the course of a week-long intensive course and delivered to blended (virtual and traditional) classrooms of students designers. Surveyed students were all enrolled in engineering degree programmes delivered at the University of Calabria:

- a classroom of twelve students attending the 'Industrial Design' course, held in 2007/08. Such experience started from a proposal to generate a concept for 'an innovative bookcase for a living room' [5];
- a class of 110 students, divided into six classrooms of no more than twenty students each, attending the 'Computer Aided Design' course, held during 2005/06. The experience was based on the design of 'a household electrical appliance for differentiated waste disposal' [6];
- a class of eighty students, divided in four classrooms of twenty students each, attending the 'Computer Aided Design' course, held during 2004/05. The experience was based on the design of 'an innovative vehicle to be used exclusively in shopping centres, airports or campuses'. Main characteristics of the methodology and the depicted scenario are presented in [30].

Each classroom has been regarded as an educational environment where product concept design has been developed; the teacher played the role of CDM and concept buyer/user, while students acted as CDG/EDT members.

4.2 The Concept Design—Thinking Style Inventory (CD-TSI)

The fifty items on the CD-TSI require respondents to think about their ways of designing during ten typical design situations (see Table 4). The situations proposed to respondents are strictly connected with the stages of a design process (questions 2, 4, 5, 9), with the approach of designers to collaboration (1, 3, 10) and with each personal way of designing (6, 7, 8). Without reflecting about their own personal designing processes, subjects would not be able to complete the inventory. In each situation, the meta-thinking process is structured for respondents since they need to reflect in a comparative mode on their ways of designing. Respondents are asked to rank order their preferred ways of designing, pitting five alternative thinking behaviours against each other on each of the ten proposed design situations to determine their overall designing style profile. Each item has five alternatives using a Likert-scale from 1 to 5 where 1 signifies designing behaviour that is 'least like me' and 5 signifies 'most like me'. Each of the five alternatives on each of the ten items must be ranked in order of preference. The set of the five sums of values on each column of the inventory (the scores) represents the thinking style profile for each student in the sample. Calculated scores for each individual can be interpreted according to instruc-

Table 4. The Concept Design—Thinking Style Inventory (CD-TSI)

Situation: 'How do you think when . . .'	1	2	3	4	5
1 . . . formulating a design problem?	I prefer to apply known and proven principles and models	I need to follow a question- driven approach	I consider many options	I likes to be different, I prefer my own approach	I prefer a heuristic approach rather than an algorithmic one
2 . . . searching for a concept vision?	More likely to build on ideas of others, less interest in being original or inventive	I focalize on questions about objectives and requirements of the product	I enjoy dealing with several ideas at once, I divide attention among competing visions	I prefer to search a concept vision alone, less consulting with others on views	I value originality, I like to play with ideas and to be imaginative
3 . . . clarifying a design task?	I tend to reveal 'facts' rather than possibilities that can be created from them	I ask questions about task's objectives, constraints and limitations	I like to investigate all possibilities already on the table	I define and offer my personal ideas on the task rather than to be affected by others' views	I need to visualize possible task outputs through sketches and preliminary drawings
4 . . . designing product functionality?	I prefer to work on well defined and well understood product functionality	I inquire into main functional aspects of the product design	I look for functionality with respect to many different use contexts	I rely on my intuition and my problem solving skill	I look for original and unusual product functionality
5 . . . designing product shape and geometry?	I focus on past experience, relying on similarities with known artefacts	I ask 'what if?' questions to come up with design proposals	I feel comfortable raising alternative shapes and geometries	I tend to minimize distractions to cope with difficulties in designing	I look for original and unusual shapes and geometries
6 . . . retrieving knowledge for a design task?	I rely on other designers' knowledge to complement mine	I search out knowledge and decide where it can be useful	I consider multiple reservoirs of expertise that can be tapped	I rely on my own knowledge which I alone can access	I challenge myself to reject routine knowledge and the obvious
7 . . . looking for perspectives or use contexts?	I value views and opinions of others and rely on their contributions	I question proposals and assumptions other designers rest on	I prefer to explore many ideas to depict different use scenarios	I focus on creating a personal perspective on the base of some usage scenarios	I broaden my thought process, even if it could be more easily distractible
8 . . . searching for product experience / emotions?	I focus more on others' emotional / experiential issues	I inquire which feelings strongly influence our perceptions	I investigate various emotional reactions influenced by the product	I am less interested in others' emotional / experiential issues	I value unusual emotional reactions
9 . . . searching for a solution to assemble product components?	I'm more likely to change my solutions to suit different situations proposed by others	I ask questions correlated with performance in obtaining design solutions	I try to explore many different solutions in designing component interfaces	I'm less likely to change or adapt my solutions to situations proposed by others	I pursue extreme thinking and increase tolerance for difficulties in designing interfaces
10 . . . debating and evaluating ideas / solutions?	I tend to readily accept the first plausible option	I feel comfortable when all objections and questions are answered	I prefer to consider the full range of options	I look for good reasons to defend my position and possibly persuade others	I like to imagine ideas / solutions within future use contexts

tions established by Zhang and Sternberg [22] to identify patterns of thinking styles for individuals and groups. The CD-TSI was indirectly validated by relying on the validity of the Sofo's TSI [23]: a PBL test experience was preliminarily conducted on a classroom of thirty students gathering data with both the CD-TSI and the Sofo's TSI; students' profiles turned out to be similar in both cases.

5. Results and discussion

To study the reliability of the CD-TSI, a Cronbach a analysis has been conducted on the raw data applied to each of the five styles. As shown in Table 5, the alpha levels were in the modest to very good range for all subscales. More important is that higher values of alpha coefficients on all subscales can indirectly confirm the reliability of awareness of students in their thinking styles.

In order to answer the first research question, pre-experience and post-experience means, standard deviations and range of given values for each com-

Table 5. CD-TSI subscale Cronbach a coefficients

Subscale	Items	a coefficients
Conditional	1a to 10a	0.854
Inquiring	1b to 10b	0.79
Exploring	1c to 10c	0.562
Independent	1d to 10d	0.631
Creative	1e to 10e	0.837

Table 6. Pre- and post-experience descriptive statistics for CD-TSI

		Conditional	Inquiring	Exploring	Independent	Creative
Pre-experience	Mean	25.500	33.500	34.333	28.750	27.833
	Standard deviation	5.962	6.142	3.798	5.101	7.530
	Range	18	21	11	19	25
	RSD (%)	23.38	18.33	11.06	17.74	27.05
Post-experience	Mean	26.750	33.833	32.500	30.000	26.917
	Standard deviation	8.946	7.791	5.760	6.223	8.372
	Range	25	24	21	19	22
	RSD (%)	33.44	23.03	17.72	20.74	31.1

Table 7. Differences in thinking style preferences (pre- and post-experience).

How do you think when . . .

Situation	Thinking preferences	Pre-experience mean value	Post-experience mean value	Sig.
. . . clarifying a design task?	I define and offer my personal idea on the task (independent).	4.17	2.09	0.03
	I accept others' proposals (conditional).	2.01	3.74	0.0164
. . . debating and evaluating ideas/solutions?	I offer my personal evaluation (independent).	4.42	1.75	0.049
	I ask questions to better understand idea's meanings and others' evaluations on it (exploring).	2.17	3.73	0.0248
	I tend to be affected by others' evaluations (conditional).	2.33	3.42	0.031

ponent of the thinking style profile have been calculated. Afterwards, these values have been statistically analysed through ANOVA techniques and relative standard deviation (RSD, i.e. the standard deviation expressed as a percentage of the mean). The use of such techniques is largely consolidated in scientific literature in the field [15, 24].

ANOVA shows no statistically significant differences between the pre-experience and post-experience means on the five thinking styles, thus indicating similar average profiles for both the pre- and post-experience data (see Table 6).

Results highlight that the thinking style profile of the design students can generally be described as a high preference for seeking multiple perspectives and asking questions (as the exploring and inquiring preferences returned the highest means). The scores on preferences for independence and creativity were also similar while the least preferred thinking style was the conditional style, indicating that students least prefer to conform to existing models and principles when doing design work.

Overall, results of statistical analyses of pre- and post-survey data show an increase of diversity of thinking style preferences in terms of relative standard deviation from the mean value of each thinking style in the CD-TSI. This finding is therefore deemed to affirmatively answer the first research question.

Regarding the second research question, analyses have been conducted on all items of the CD-TSI in order to reveal possible changes in the preferences of thinking styles during particular design situations. In this sense, ANOVA tests reveal a change in the preferences of thinking styles reported by students engaged in PBL experiences. Statistically significant differences were found on 5 of the 50 CD-TSI items tested and related to two of the ten proposed situations. The two situations are: 'How do you think when clarifying a design task?' and 'How do you think when debating and evaluating ideas/ solutions?' ANOVA confirms that these differences are significant at $p < 0.05$ (see Table 7).

The close clustering of significance is interesting since statistical significance occurs at both ends of the design process, the clarification and evaluation phases. The academic instructors emphasized the critical importance of the beginning and concluding phases of design stressing that they are the critical moments or tipping-point opportunities for significant creativity to occur. In particular De Bono's [31] six thinking hats strategy was employed consistently during these stages of the simulations to ensure an emphasis on multiple perspectives.

Survey results allow us to answer affirmatively to both research questions and to confirm that the PBL experience positively influences students' openness to diversity and collaborative work.

5.1 The pilot test

To test our hunches about the improved empathy displayed by students, a further pilot was conducted on a new sample of design students by using the PBL experience approach previously described. The new sample subject to the PBL experience was a classroom of fourteen students designers enrolled in 2007/08 in the engineering degree programme delivered at the University of Calabria.

Table 8. CD-TSI subscale Cronbach a coefficients for the new sample of fourteen student designers

Subscale	Items	a coefficients
Conditional	1a to 10a	0.855
Inquiring	1b to 10b	0.774
Exploring	1c to 10c	0.607
Independent	1d to 10d	0.777
Creative	1e to 10e	0.834

Table 9. CD-TSI subscale Cronbach a coefficients for pre- and post-test data on the new sample of fourteen students designers

Subscale	Pre-experience	Post-experience
Conditional	0.344	0.855
Inquiring	0.602	0.774
Exploring	0.404	0.607
Independent	0.464	0.777
Creative	0.810	0.834

Statistical results confirm the previous ones collected with the sample of 202.

In Table 8 the alpha levels of a Cronbach a analysis are given. Results highlight the reliability of the awareness of students in their thinking styles.

For a deeper study of the internal consistency of the CD-TSI, Cronbach a analyses were conducted both for pre- and post-test on the raw data applied to each of the five styles (see Table 9).

The repeat Cronbach α scores consistently increase, across all five areas and in a uniform manner, compared with the first set. It seems that because all alpha coefficients have gone up almost uniformly and consistently that an even impact or change has occurred in the students' thinking in relation to the interpretation of the CD-TSI questions and paradigm. This is almost difficult to believe as the intervention must have been very powerful to show this uniformly consistent change of scores at such magnitude. The fact that the second set of scores is uniformly more consistent and less variable can indicate both improved awareness in students' thinking styles after the PBL experience and increased understanding of the context and background to the questions posed in the CD-TSI.

In Table 10, pre-experience and post-experience means, standard deviations, range of given values and RSD for each component of the thinking style profile have been calculated.

Results of statistical analyses for the new sample confirm the results already highlighted in the previous survey, i.e.:

- the thinking style profile of the design students is characterized by the preference for seeking multiple perspectives and asking questions;
- there was an increased diversity of the thinking style preferences in terms of relative standard deviation in post-test results; thus continuing to answer the first research question positively.

In respects to the second research question, changes in the preferences of thinking styles reported by students engaged in PBL experiences were found on one item tested. In the situation 'How do you think when clarifying a design task?' the pre-experience mean value for the item 'I define and offer my personal idea on the task' (independent) was 4.12 while in the post-experience the mean value was equal to 2.72. This difference is confirmed by ANOVA at sig = 0.004.

6. Conclusions and future study

The results from this study do not necessary imply a permanent change in student thinking style profile, but they do show that a PBL experience where students act as real designers during a collaborative design project can contribute to increased awareness of their thinking styles, especially where the learning structures require them to practise diverse ways of thinking. The results are therefore in contrast to other published literature that suggests that thinking styles are relatively fixed and difficult to change. In this study it became clear that students were able to adapt their styles of thinking during two key phases of a learning simulation under the care of instructors who were able to provide feedback and encouragement to think in different ways. Whether the same students can transfer this learning

Table 10. Pre- and post-experience descriptive statistics for CD-TSI on the new sample of fourteen student designers

		Conditional	Inquiring	Exploring	Independent	Creative
Pre-experience	Mean	25.64	34.64	35.64	27.93	26.07
	Standard Deviation	5.665	6.428	4.830	5.151	8.251
	Range	18	21	15	19	28
	RSD (%)	22.09	18.03	13.55	18.44	31.65
Post-experience	Mean	25.43	34.79	33.64	27.93	28.21
	Standard Deviation	8.907	7.567	6.046	7.800	8.460
	Range	25	24	21	25	22
	RSD (%)	35.03	21.75	17.97	27.93	30.00

to real work situations where there are different pressures and generally the absence of a mentor or teacher to encourage them to think laterally at key points is a question for further study.

The results from this study show that a PBL experience can help the meta-cognitive process of highlighting personal thinking styles during design where explicit requirements for thinking in diverse styles are created. This initial exploratory study gives optimism for the education of design students as it points to some success in teaching openness to multiple perspectives and the cultivation of an open mind as the basis for creativity. Since the results show promise, more extensive studies are being conducted for a deeper understanding of whether the changes that occurred in the students' thinking are due to a better interpretation of the CD-TSI questions and paradigm or to an increased awareness in students' thinking styles.

Finally, a future study could evaluate the creativity of the design products of students who have experienced creative simulations with the products of a control group.

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