Constructive Controversy in Engineering Undergraduate, Masters, Doctorate, and Professional Settings[1]

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Abstract

Constructive Controversy has been incorporated as part of the preparation of participants in academic programs in engineering since the early 1980's. It was introduced initially in undergraduate programs and more recently in Masters and Doctorate programs as well as Professional Masters programs and faculty professional development programs. The importance of developing constructive controversy skills for professionals is increasing given the rapidly increasing complexity of decisions and the paramount importance of innovation. We argue that constructive controversy is an excellent approach for operationalizing innovation as a social process. In this paper we document the approach through: 1) briefly reviewing the development of constructive controversy including the social interdependence theoretical framework and the details of this type of cooperative learning approach; 2) providing instructional guidelines, references and resources; and 3) reviewing current case examples in educational and professional development settings.

Finally, a case study shows how constructive controversy has been implemented in a course on engineering grand challenges that adopts collaborative problem solving as its main pedagogy. Students worked in teams of four, with the assistance of their peer tutor, generated solutions to two wicked or ill-structured problems related to the engineering challenges in one semester. Two teams need to work on their own solution initially and produce an integrated solution through the constructive controversy process at the end. The eight student teams were found to approach constructive controversy in three different styles, namely, "consensus and combination", "confrontation and synthesis", and "forcing and following". Among them, "confrontation and synthesis" produced the best integrated solution and the highest self-reported gains in most of the learning outcomes whereas "consensus and combination" resulted in harmonious inter-team relationship and the highest self-perceived learning gains in collaborative problem solving. Lessons learned in this case would be the initiatives for the continuous improvement of the course.

Introduction

Constructive controversy is a theoretically grounded and empirically tested teaching approach that has been practiced in engineering education settings since the early 1980s, shortly after the constructive (or structured) controversy approach was proposed by Johnson and Johnson (1979). Constructive controversy is a formal cooperative learning model, which is facilitated in groups with four members typically and occasionally six members. Pairs are assigned perspectives that they prepare, present, and

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discuss within a cooperative goal framework of achieving consensus on a decision or recommendation or, at a minimum, agreeing on the best arguments on all sides. Constructive controversy, like other cooperative learning approaches, is grounded in Lewin's social interdependence theory as articulated by Deutsch (1949). This theory posits three types of inner group dependencies when working towards a goal, and advocates for the first as most conducive to positive learning gains. *Positive interdependence* exists when there is a positive correlation among individuals' goal attainments; individuals perceive that they can attain their goals if, and only if, the other individuals with whom they are cooperatively linked attain their goals. *Negative interdependence* exists when there is a negative correlation among individuals' goal achievements; individuals perceive that they can obtain their goals if and only if the other individuals with whom they are competitively linked fail to obtain their goals. No interdependence exists, and thus efforts are individualistic, when there is no correlation among individuals' goal achievements; individuals perceive that the achievement of their goals is unrelated to the goal achievement of others. Significant research extols the benefits of *positive interdependence*.

Since being introduced into the engineering education community in the early 1980's, cooperative learning and constructive controversy have been incorporated into engineering education curricula. Constructive controversy has been applied in undergraduate engineering courses at the University of Minnesota using topics such as the best algorithm for finding the roots of a polynomial (bisection, Newton-Raphson, guess and check, etc.), addressing issues such as land use (preserve versus manage), role of regulations in hazardous waste management (more versus fewer), electrical energy production, and many others. In professional masters programs, especially the Management of Technology and Infrastructure Systems Management and Engineering, constructive controversy has been used with a variety of relevant and timely topics. Constructive controversy has been implemented in engineering grand challenges courses for undergraduate students of all majors (i.e., engineering, science, business, and humanities) at the Hong Kong University of Science and Technology. Constructive controversy has also been used in engineering education graduate courses related to leadership, policy, and change and history and philosophy of engineering education. At the faculty professional development level constructive controversy workshops have been conducted at many universities, most recently at Nanyang Technological University in Singapore and Michigan State University in East Lansing, Michigan; as well as professional meetings, such as the workshop at the 2009 ASEE/IEEE Frontiers in Education Conference (Matusovich and Smith, 2009). We argue for the continued use and spread of constructive controversy because constructive controversy can play a significant role in fostering innovation.

Constructive Controversy and Innovation

> **Controversy with Civility** – recognize that differences of viewpoint are inevitable and that such differences must be aired openly but with civility. Civility implies respect for others, a willingness to hear about each other's viewpoints, and the exercise of restraint in criticizing the views and actions of others. Controversy can often lead to new, creative solutions to problems, especially when it occurs in an atmosphere of civility, collaboration, and common purpose (Astin and Astin 1996).

Controversy exists and being able to engage in productive, respectful navigation of controversy can lead to beneficial outcomes. We argue that innovation is one such positive outcome. The claim that constructive controversy provides a framework and approach for fostering innovation is relatively new in the cooperative learning literature; however, it is indirectly supported by earlier literature (March, Sproull and Tamuz, 1991). There is extensive evidence that constructive controversy promotes individual learning both from the Johnson and Johnson cooperative learning framework discussed in this chapter as well as from the argumentation literature, for example, Kuhn, D., Shaw, V., and Felton, M. (1997), Jonassen, D. H., Cho, Y. H., Kwon, K., Henry, H., Easter, M., Shen, D., et al. (2009), and Jonassen, D.H., and Kim, B. (2010).

Bledow, et.al. (2009) argue that a dialectic process is central to innovation. For example, they claim, “In the tradition of dialectic thinking, organizational innovation can be conceptualized as a dialectic process, the resulting innovation being a specific instance of a synthesis”(p. 311). Our view is that the constructive controversy process provides a well-documented process for operationalizing the synthesis aspect and an evidence-based practice for facilitating the discussion. Bledow, et.al. (2009) also embrace the March, Sproull and Tamuz (1991) claim about the importance of balancing exploration and exploitation. Specifically they argue that “Innovation requires the regulation of exploration and exploitation and their antecedents (e.g., divergent and convergent thinking, learning and performance orientation).” Our work builds on March’s (1991) emphasis on exploration vs. exploitation and embraces the fundamental importance of the explore-exploit trade-off (Smith, 2013). Complexity theorists such as Page (2009) also embrace the importance of the explore-exploit trade-off.

Essentially, creative synthesis is at the heart of innovation. Brian Arthur (2009) in describing the nature of technology, emphasized the centrality of combinations. He offered the following definition of technology:

1. A means to fulfill a human purpose
2. An assemblage of practices and components
3. The entire collection of devices and engineering practices available to a culture

and emphasized three fundamental principles:

1. All technologies are combinations
2. Each component of technology is itself in miniature a technology
3. All technologies harness and exploit some effect or phenomena, usually several.

Similarly, Hargadon (2003) argues that “In fact, innovation is really about creatively recombining ideas, people, and objects from past technologies in ways that spark new technological revolutions.”

The constructive controversy approach as described in this chapter and in overall in this book provides a well-documented procedure for achieving creative combinations through striving for synthesis.

Development of Constructive Controversy

Constructive controversy was proposed by the Johnson and Johnson cooperative learning group at University of Minnesota in the late 70s and the approach was well supported from theoretical, empirical and practical perspectives (Johnson and Johnson, 1987). In a typical constructive controversy process, students are required to study and prepare a position to a controversial issue, present and advocate for their position, refute opposing arguments, reverse perspectives, and finally create a synthesis that group members can agree upon based on the best available evidence (Johnson and Johnson, 1988). Different from concurrence-seeking in which students could neglect any conflicts and compromise to reach a consensus, constructive controversy asks students to state their disagreements openly and critically evaluate each other's position (Smith, Johnson and Johnson, 1984). Constructive controversy is also significantly different from a debate as the former does not encourage students to win over arguments but to generate a synthesis based on both positions at the end (Johnson and Johnson, 1988).

As an instructional method, constructive controversy has generated benefits in improving student learning. Early in the 1980s, Smith et al. (1984) compared the effects of constructive controversy with concurrence-seeking discussion in an engineering class and found that constructive controversy resulted in higher level cognitive processing than the control group. Their study also showed that students' relationship and liking to the group were not affected by the "controversy" which was traditionally perceived as harmful to a good relationship. D'Eon, Proctor and Reeder (2007) studied the difference between constructive controversy and open discussions, and found that students in the constructive controversy group changed their opinions more often and sustained the changes after a few days while students in open discussion groups tended to drift back to their original standpoints.

In the discussion on engaging pedagogies in engineering education, Smith and his associates (2005) suggest that constructive controversy contributes to the group process for engaging students working in formal cooperative learning in a problem-based learning environment. Deliberately structuring the "controversy" would enable instructors to move beyond the traditional group work format, i.e., simply assigning a problem to a group of students, towards the authentic cooperative learning group that emphasizes interdependence, face-to-face interaction, individual accountability, teamwork skills, and group processing (Smith, Johnson and Johnson,1981c).

Stepping outside constructive controversy and looking more broadly at cooperative learning as a whole, the evidence supporting such approaches continues to mount; the empirical and theoretical evidence supporting cooperative learning is vast. During the past 90 years, over 350 experimental studies have been conducted in college and adult settings comparing the effectiveness of cooperative, competitive, and individualistic efforts. These studies have been conducted by a wide variety of researchers in different decades with different learner populations, in different subject areas, and in different settings. More is known about the efficacy of cooperative learning than about lecturing, the fifty-minute class period, the use of instructional technology, or almost any other aspect of education. From this research you would expect that the more students work in cooperative learning groups the more they will learn, the better they will understand what they are learning, the easier it will be to remember what they learn, and the better they will feel about themselves, the class, and their classmates. The multiple outcomes studied can be classified into three major categories: achievement/productivity, positive relationships, and psychological health. Cooperation among students typically results in (a) higher achievement and greater productivity, (b) more caring, supportive, and committed relationships, and (c) greater psychological health, social competence, and self-esteem (for details see Smith, Sheppard, Johnson & Johnson, 2005; Johnson, Johnson & Smith, 1998 and 2007).

Instructional Guidelines, References and Resources

Constructive controversy is most commonly used to engage learners in topics where there are multiple perspectives and the advocacy with an overall context of inquiry can lead to deeper understanding. The students typically have experience with formal cooperative learning and then they are introduced to the definition of controversy: When one person's ideas, information, conclusions, theories, or opinions are incompatible with those of another – and the two seek to reach an agreement (Johnson and Johnson, 1979). Implementations of constructive controversy often include a series of steps executed in pre-determined order with the goal of helping learners see the multiple perspectives. While there is not a set amount of time required for constructive controversy, it is important that the topic selected can be explored in sufficient depth and that the end product can be created in the time allotted. As a brief overview, the steps of constructive controversy include:

1. Students are assigned to groups of four and the group is given an assignment (joint report, classroom presentation, public dialogue, etc.) to be completed together. The assignment should focus on an issue where there are multiple perspectives and as an outcome each group is required to reach a mutually agreeable conclusion, decision or action.
2. Within the groups, the students are assigned to pairs. One pair is initially assigned one position or perspective and the other pair an opposing perspective.
3. Each pair of students researches the issue and prepares arguments for their perspective. This can be completed before the class period as homework or in class if appropriate for the assigned activity and time.
4. One pair presents their argument while the other pair listens and takes notes without interrupting.
5. They exchange roles such that the other pair presents and arguments.
6. The pairs reverse perspectives and repeat the alternating argument process such that each pair must now adopt and argue for a perspective counter to the one they were assigned at the start.
7. Together the pairs synthesize arguments and reach a common resolution.

Several instructional references describe this process in greater detail (Johnson and Johnson, 2009). It is important that instructors monitor the process to be sure that students engage intellectually and respectfully with each other. Discussing some rules in advance is often helpful. The examples from engineering (undergraduate and graduate) that follow, illustrate different ways that constructive controversy can and has been executed.

Cooperative Learning and Constructive Controversy in Engineering Education

Cooperative learning was introduced to engineering educators in the U.S. at the 1981 Frontiers in Education (FIE) Conference in Rapid City, SD (Smith, Johnson, Johnson, 1981a); a little over 30 years after Morton Deutsch's pivotal articles (Deustch, 1949a, 1949b). The 1981 paper was based on David and Roger Johnson's pioneering work (Johnson and Johnson, 1974) as identified by Karl Smith in the mid-1970s as a promising practice for engineering education. The history of the emergence of cooperative learning in engineering is summarized in Smith (2011). Currently, cooperative learning is the most widely adopted innovative practice in engineering education, and has been embraced as well in higher education (DeAngelo et al., 2009).

Shortly after the introduction of cooperative learning in engineering education, constructive controversy was implemented (Smith, Johnson and Johnson, 1982) and studied (Smith, 1984; Smith, Peterson, Johnson and Johnson, 1986). The Johnson and Johnson conceptual cooperative learning model resonated with employers who were concerned about graduates' professional skills, especially teamwork skills, and there was mounting pressure to change engineering education. Constructive controversy was received with a lot of interest due, in part, to the strong theoretical support and the growing body of empirical evidence. A 1984 FIE workshop by Johnson and Smith (1984) won the Helen Plants Award for the best non-traditional session. At about this time Greenhaven Press introduced their Opposing Viewpoints series, which provided additional resources. Smith continued to make extensive use of the approach in his civil engineering courses (especially around environmental controversies), in College of Liberal Arts Honors Seminars and Colloquia, and continues today in his graduate courses. Recently, Neil Mickleborough, Tracy Zou and other colleagues in the Center for Engineering Education Innovation at Hong Kong University of Science and Technology implemented constructive controversy in a course on engineering grand challenges that adopts collaborative problem solving as its main pedagogy (Zou, Mickleborough and Leung, 2012).

This implementation of constructive controversy in undergraduate engineering education is described in the below mentioned case study. Before that, some examples of applying constructive controversy in varying academic educational settings are briefly described.

Constructive Controversy in Professional Master's Programs

Constructive controversy has been a principal pedagogy in two professional master's programs at the University of Minnesota since the early 90s. The programs are Management of Technology and Infrastructure Systems Management and Engineering, which are executive programs for full time working engineers.

The framing of the constructive controversy involves the typical Johnson and Johnson approach and guidelines as well as Garvin and Roberto's (2001) framing of decision making as an advocacy or an inquiry process (table 1):

	Advocacy	Inquiry
Concept of decision making	A contest	Collaborative problem solving
Purpose of discussion	Persuasion and lobbying	Testing and evaluation
Participants' role	Spokespeople	Critical thinkers
Pattern of behavior	Strive to persuade others Defend your position Downplay weaknesses	Present balanced arguments Remain open to alternatives Accept constructive criticism
Minority views	Discouraged or dismissed	Cultivated and valued
Outcome	Winners and losers	Collective ownership

Table 1: typical features of advocacy and inquiry

In other words, if the goal is understanding, then an inquiry approach would be best; whereas if the goal is winning, then an advocacy approach would be best. Constructive controversy is overall an inquiry approach that embraces advocacy in order to get a better understanding of the best arguments on all sides.

Here is the description of the project (from the syllabus):

> *Constructive Controversy Discussion: Each Study Group will prepare (i.e., do the background reading and research), plan (i.e., identify 2-4 positions or perspectives), conduct (i.e., follow the constructive controversy discussion procedure for about 45 minutes) and synthesize (i.e., write a brief report) during a study group session. See Johnson, Johnson and Smith (2000) for explanation of procedure. I'll model the Constructive Controversy Discussion procedure during a class session and work with Study Groups to select topics.*

Typical topics that are selected by the participants include:

- Make project certification, e.g. Project Management Professional (PMP), a part of the graduate program?
  - Yes
  - No
- Who makes the best project manager?
  - Generalist
  - Specialist
- Brooks' Law: "adding resources to a late project makes it later"
  - Right on!
  - Way off!
- Scope Creep
  - Parkinson's Law: Work expands to fill the time available for completion (manageable)

  - Progressive refinement rules! (unavoidable)
- Peters: Tomorrow's corporation is a collection of projects"
  - Accurate portrayal
  - Inaccurate portrayal
- The future work environment is remotely distributed
  - Future is already here (it's just not evenly distributed) - Gibson
  - Fad

Alumni of the program note that their use of constructive controversy continues after the course ends and is one of the ideas they implement in their workplaces. One of the principal arguments for the use of constructive controversy is the centrality of advocacy within an inquiry framework for innovation.

Constructive Controversy in Graduate Engineering Education Courses

Leadership, Policy and Change

In the spring semester of 2007 a Purdue University School of Engineering Education foundation course titled *Leadership, Policy and Change* was offered for the first time. Although offered through the College of Engineering, the course focused more broadly on Science, Technology, Engineering, and Mathematics (STEM) fields. Holly Matusovich was a student in this class and Karl Smith was one of the instructors.

The course was divided into the three modules as suggested by the title, although the themes were integrated overall. The objectives for the policy portion of the class included examining current STEM educational policies, understanding how policies can impact stakeholders and gaining familiarity with policy implementation and analysis. As part of the policy module, students participated in a constructive controversy. This activity was consistent with the aforementioned goals of the policy module as well as the overall course goal of learning about negotiation strategies and change implementation.

The constructive controversy activity was structured as both a homework and in-class group assignment. Individually students selected policy-related questions from an instructor-provided list of possible questions. Based on students' expressed interests, the instructors created teams of students. As an example of the topics, Holly's team argued the question "How serious a threat is globalization?"

Within the teams, the students self-divided into pairs. One pair adopted the pro position and one the con position. Outside of class, the pairs and teams met to share resources and prepare arguments. Ultimately, each pair prepared a pro and a con argument knowing they would ultimately present both sides. In class, each team participated in a constructive controversy activity while the balance of the class observed.

In this application, constructive controversy served as a way to teach students about effective arguing within the setting of exploring policy. Students had the opportunity to actively engage with others to consider different stakeholder perspectives on the same issue.

History and Philosophy of Engineering Education

In the fall semester of 2007, a course titled *History and Philosophy of Engineering Education*, a foundation course in the Engineering Education PhD program at Purdue University was taught for the first time. Karl Smith was one of the instructors and Holly Matusovich was a faculty apprentice for this course. Knowing that many of our students were future engineering educators and researchers, this course was designed to teach students content as well as promoting the deeper thinking and argument formation skills needed by researchers. Course objectives centered on understanding how to read and critically examine the arguments made by others and how to develop and articulate one's own arguments and perspectives. Constructive controversy was a good fit with these goals.

Constructive controversy was conducted as an in-class activity although students had readings related to the controversy topic as a homework assignment prior to the class. The topic related to a primary course theme called "What is engineering?"

On the day of the activity, we introduced students to constructive controversy both as a teaching tool by including some theory and benefits, and as a learning activity in which they would participate that day. The students were divided into groups of four. The groups of four were subdivided into pairs and each pair was assigned a pro or con position to argue initially. The students then watched a video clip of an engineering design team at work in a professional context. Students were instructed to make notes supporting the activities represented in the video as "engineering activity" (pro) or "not engineering activity" (con). At the conclusion of the video clip, the students began active constructive controversy.

In this example, constructive controversy provided students an opportunity to actively practice developing and articulating their own arguments while analyzing and responding to arguments made by their peers. It also provided an opportunity to challenge standard definitions for what something is (e.g., What Is engineering?) as a way to think about that thing in a new way.

Summary of Case Examples

In this section we described several case examples. Although they were not originally conceived with the idea of promoting innovation, we can look back at them with an innovation lens. In addition to promoting the ability to engage in controversy with civility, we may have helped students see 1) how synthesis and combination (previously described attributes of innovation) result in product outcomes that are more beneficial to multiple stakeholders (Leadership, Policy, and Change example), 2) how important it can be to challenge previously accepted definitions (What Is engineering? From History, and Philosophy example). The following case study shows 3), how constructive controversy enhances the quality of team output, and more importantly the essential role of confrontation and synthesis in the processes of generating innovative solutions.

Case study: Students' approaches in constructive controversy and their learning outcomes in a course on engineering grand challenges in Hong Kong – T.X.P. Zou

Introduction

Engineers nowadays are often required to work collaboratively with people of different backgrounds in order to solve complex problems. The abilities to solve problems, consider the solutions in a societal context, as well as to function in multidisciplinary teams are regarded as important attributes that an engineering graduate of any major should possess (ABET, 2010). The newly established course on engineering grand challenges in HKUST as a school-sponsored course intends to develop these abilities in students through providing them with the appropriate collaborative structure.

Constructive controversy was chosen not only because it is proved to be a useful teaching method to facilitate students' learning, but also because it could help students understand various perspectives on complex issues and perform higher-level cognitive processing (Smith et al., 1984). Both of these benefits from constructive controversy were critical to the generation of an innovative solution to the grand engineering challenges. Felder and Brent (2003) suggest that the use of constructive controversy as an instructional method could effectively address some of the intended learning outcomes specified in Engineering Criteria 2000, for example, "the ability to understand the impact of engineering solutions in a global and societal context" (ABET, 2010).

This study implemented constructive controversy in a newly established course on engineering grand challenges. The idea of "grand challenges" comes from U. S. National Academy of Engineering which announced 14 challenges for engineers in the 21st century, ranging from humanity to flourish (NAE, 2008). Under a collaborative problem solving pedagogy, the course aims to develop students' abilities to identify and solve real-world problems collaboratively. Since its launch in the spring of 2011, the course has been undergoing two rounds of continuous improvement based on research, with each a new approach introduced to enhance students' learning. The first enhancement was the introduction of peer tutors, and the current was the adoption of constructive controversy to provide students with a clear and formal structure in class to learn and practice collaborative problem solving. These improvement initiatives were partially based on the literature emphasizing the importance of scaffolding in teaching problem-based learning (Prince and Felder, 2006; Yadav, Subedi, Lundeberg and Bunting, 2011), and partially based on previous observations about students' weaknesses in critical thinking, balancing arguments, and conflict resolution in the local context. Scaffolding is the support given during the learning process which is tailored to the needs of the student with the intention of helping the student achieve his/her learning goals (Sawyer, 2006).

This study focuses on the following research questions: (1) what was the experience of students in the constructive controversy process? (2) Whether the experience of students affected their learning outcomes and in what ways? (3) What promoted and inhibited the positive effect of constructive controversy in problem-based learning? This investigation would provide insights into the relationship between how students approached constructive controversy and their learning outcomes. The local context in this study may also be of interest to scholars since the relevant literature has been mostly reported in a western environment. It will be useful to examine the effect of constructive controversy in a Chinese context, where students were generally characterized as valuing harmonious relationship (Hofstede and Hofstede, 2005) and in favor of indirect communication (Morris et al., 1998). These features might lead to different outcomes of constructive controversy compared to those in a Western context.

The course on engineering grand challenges

The course on engineering grand challenges offers an excellent platform for the experimentation of constructive controversy. The course has been relying on the collaborative problem solving pedagogy since its launch. Students are required to work in teams collaboratively to propose solutions to two real-world engineering challenges. Both of the challenges were prepared and presented by subject-matter experts in the relevant industry or academic fields. After completing the course, students should be able to (1) identify the key issues involved in two real-world engineering problems by obtaining information from experts and the literature; (2) analyze these problems from multiple dimensions and angles including feasibility, scalability and sustainability; (3) suggest and evaluate solutions to these problems by working collaboratively and through constructive controversy; and (4) present and defend their solutions orally and in writing.

The course has been experiencing a number of innovations since its first implementation in the spring of 2011. In the first run, the course promoted collaborative problem solving and required students to work in multidisciplinary teams. Three assessment rubrics, i.e., the rubrics for presentation, reports and teamwork, were developed to evaluate performance of students by self, peers, and instructors. During the second operating in the fall of 2011, peer tutors were introduced to form a multi-layered learning environment where peer tutors provided coaching to student teams (Mickleborough, 2011; Zou, Ko and Mickleborough, 2011). All peer tutors were recruited from students who have demonstrated good performance in the same course of previous semesters. At the third pilot of the course, constructive controversy was introduced for enhancing student learning.

It is hypothesized that constructive controversy would facilitate students to better achieve the learning outcomes because students are stimulated to work towards Learning Outcomes (1) to (4) through the processes of preparing, presenting, defending positions, and refuting opposing arguments. The collaborative problem solving skills, as stated in Learning Outcomes (3), could be reinforced through the final synthesis of the opinions from the two sides.

Settings

In the spring semester of 2012, thirty-two students were enrolled from different disciplines, including engineering (65.6%), business (9.4%), science (6.3%), and double major (18.8%). The instructor formed eight teams, each consisted of four students. The principle of assigning students into teams was to maximize the diversity of majors so that they had opportunities to work with people of different backgrounds. Five peer tutors were recruited. Three of them provided coaching to six teams, with each overseeing two teams. The remaining two peer tutors coached another two teams on an alternative basis because of timetable clash.

Training on collaborative problem solving through inquiry and leadership skills was delivered to students at the beginning of the course. Two Reference Librarians were embedded in the course and provided assistance to students on relevant areas including literature search skills. After the presentation of each challenge by the expert, students were required to attend discussion sessions in class and suggest solutions to tackle the challenges. The constructive controversy was implemented in the second challenge which was about electricity generation from clean and renewable resources. The overall challenge was divided into four specific problem areas, each of which was assigned to two teams. Instead of assigning one perspective or other to students, our design allows them to firstly generate their own ideas to solve the problem. This adaptation gives students more freedom and due to the multi-faceted nature of the grand challenges, teams working on the same topic naturally came up with very different ideas. The two teams need to work on the solutions by themselves initially and then collaboratively through the constructive controversy process to generate one integrated solution. Two 1.5-hour class sessions were arranged for the presentation and questioning between the two teams and another two sessions were set up for them to integrate the solutions. The process is shown in Figure 1.

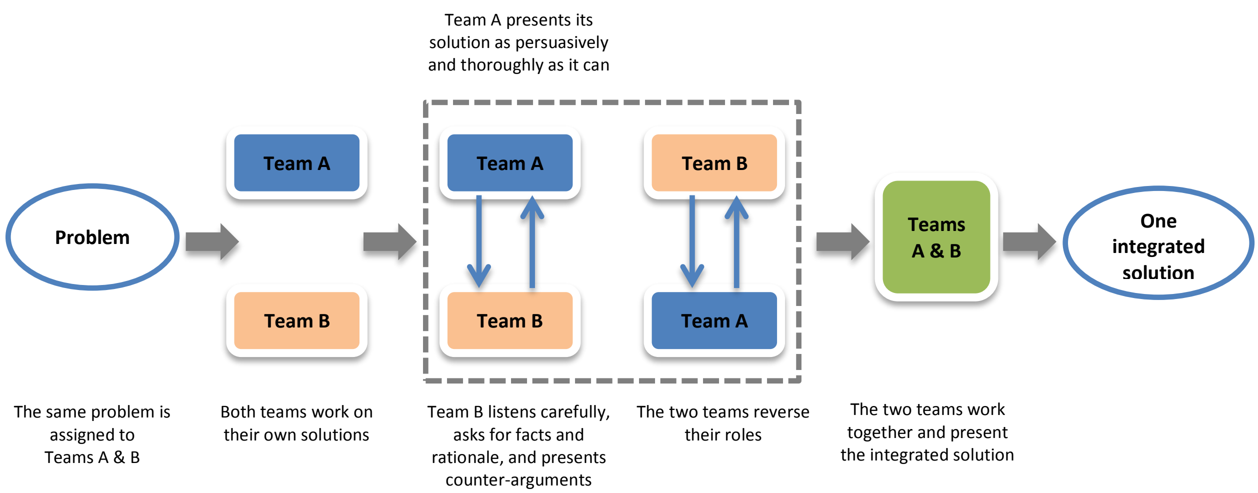

Figure 1 The process of constructive controversy in the course

Students were assessed by their performance in report, presentation and collaborative problem solving. Rubrics that have been validated in previous semesters were used in the assessment. The collaborative problem solving rubric covered critical thinking, balancing arguments, being open to alternatives, accepting constructive criticism, cultivating and valuing minority views, and taking collective ownership. These six dimensions were derived from Garvin and Roberto's (2001) model on inquiry approach in decision making. In addition, students were asked to self-assess at the beginning and the end of the course their abilities in identifying issues, solving problems, working collaboratively, and presenting and defending ideas, as reflected in the four intended learning outcomes.

Various sources of data were collected on the constructive controversy process. For example, students were asked to give written comments on "what they have done well" and "what could have been done better" in the process of working with the other team. Feedback from peer tutors was constantly sought to triangulate the data from students. At the end of the semester, focus groups were conducted with students and peer tutors respectively to obtain more feedback on the use of constructive controversy as a means to generate problem solutions.

Different styles in constructive controversy and the student learning outcomes

It was found that students approached constructive controversy in different ways even if the presentation and integration of solutions between teams were carefully scheduled in class sessions. The data collected shows three different styles, described as follows:

"Consensus and combination" – Teams A and B

Teams A and B reached consensus easily with few controversies occurring in the teams and finally combined some elements in their initial solutions to generate the final solution. Instead of proposing counterarguments and critiques after the presentation of initial solutions by each team, team members in these two teams mainly asked for clarification of facts and gradually agreed to the viewpoints of the counter-team. Students in these teams wrote the following about what they believed had been done well in the process "*we did not have any conflicts. It was easy to reach consensus*." They also emphasized that multiple perspectives had been considered and a harmonious relationship was built. Although they explicitly indicated that they had not thought critically, their overall self-evaluation on the problem solving process based on the rubric was still very high. It was also reflected in the feedback of their peer tutor, who reported these two teams were very friendly to each other and jumped to the conclusion quickly.

"Confrontation and synthesis" – Teams C and D

Teams C and D adopted "confrontation and synthesis", which was mostly close to the original essence of constructive controversy. During the presentation of the initial solution, these two teams followed the requirements to ask for facts, and present counter-arguments and rebuttals. In the focus group, team members from these two teams could clearly articulate the difference between conventional group work processes and constructive controversy. One emphasized that "*we were not combining ideas, but questioning each other's solutions before finally synthesizing the results. The other team must convince us by clear evidence".* The written comments of these two teams of students focused on multiple perspectives, efficiency, teamwork, and open-mindedness. On the other hand, they classified communication as something that the team should improve. Their peer tutor had confirmed that these two teams challenged each other's initial solutions before they started the integration process. Students also acknowledged that their peer tutor had given clear instruction on how to conduct constructive controversy.

"Forcing and following" – Teams E and F and Teams G and H

Two pairs of teams used a "forcing and following" style in the constructive controversy. Teams E and F suffered from a few of strong team members (in Team E) who were reluctant to change their initial solutions in the integration stage. Team F fought for their right to say when they tried to integrate but finally gave up as the deadline for submitting the solutions was approaching. Team E made most of the decisions in the final solutions without much involvement of Team F. Teams G and H suffered from one uncommitted team (Team G) which often failed to take responsibilities. In the focus group, team members in F complained that "*Team E was very dominating and we did not have a chance to say* *anything*" and Team H pointed out "*Team G always failed to take their promise*". The written comments of these four teams had also revealed complaints about the lack of motivation and teamwork.

Table 3 illustrates the most frequently occurring themes in each style. The comments of students were clustered and categorized. Constant comparison was conducted to determine to which cluster a particular comment should be assigned. Ten clusters emerged and were labeled as categories. Each comment was reviewed for the second time and linked to one or more categories. The frequency indicates the occurrence of the themes in the written comments in that category. A negative sign before the number indicates that the theme was classified by respondents as "things that the team could have done well" (i.e., areas of improvement).

Table 3 Themes identified in the written comments of team members

Themes	**"Consensus and combination"**	**"Confrontation and synthesis"**	**"Forcing and following"**
Consideration of multiple perspectives and a range of ideas	13	6	0
Preparation and background research	6	0	7
Communication	6	-3	1
Highly motivated and committed	6	0	-14
Harmonious relationship	5	0	0
Critical thinking	-5	2	8
Efficiency and work allocation	0	6	1
Open mindedness	4	3	2
Report and presentation skills	-12	0	-2
Teamwork and cooperative learning	0	4	-4

Student learning outcomes in different styles

It is observed that student learning outcomes were different for teams adopting a different style in constructive controversy. The report score of the first challenge was used as a baseline since it was done by student teams without collaborating with the other team while the report for the second challenge was compiled after the constructive controversy process. Each report was assessed by the expert and the instructor. Figure 2 shows the change in the report scores.

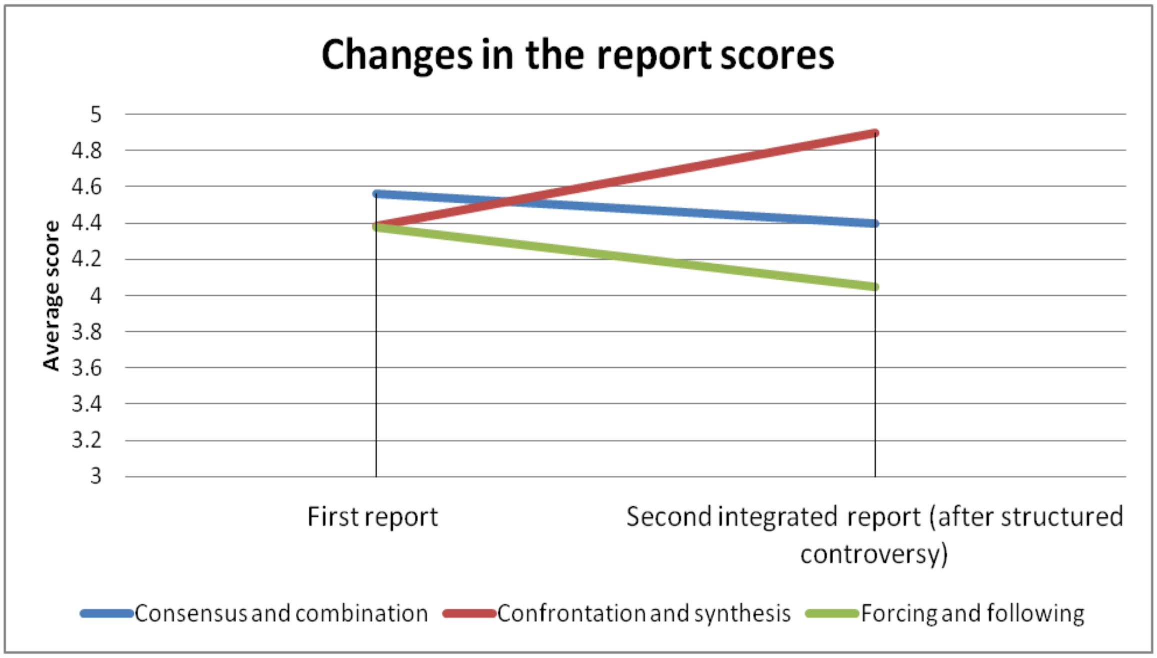

Figure 2 Changes in the report scores (on a scale of 1-5, 1 means needs work, 3 means competent and 5 means exemplary)

It was noted that teams taking a “confrontation and synthesis” approach moved from scores slightly below average to a very high score nearly reaching the full mark (i.e., 4.9 out of 5.0). Teams taking “consensus and combination” approach were above average in both of the reports while all teams taking “forcing and following” fell below average in the last report despite that one pair of teams was above average in the first report.

Differences were also noted in the self-assessment of students regarding the four intended learning outcomes. Scores for each pair of teams were averaged. The report scores had not been released at the time of the self-assessment so that the self-assessment scores were not affected by their performance score. It was found that teams taking “confrontation and synthesis” approach perceived that they learned more than other teams in most aspects whereas teams using “consensus and combination” perceived the highest learning gains in working collaboratively. Figure 3 shows the difference in the self-assessment scores.

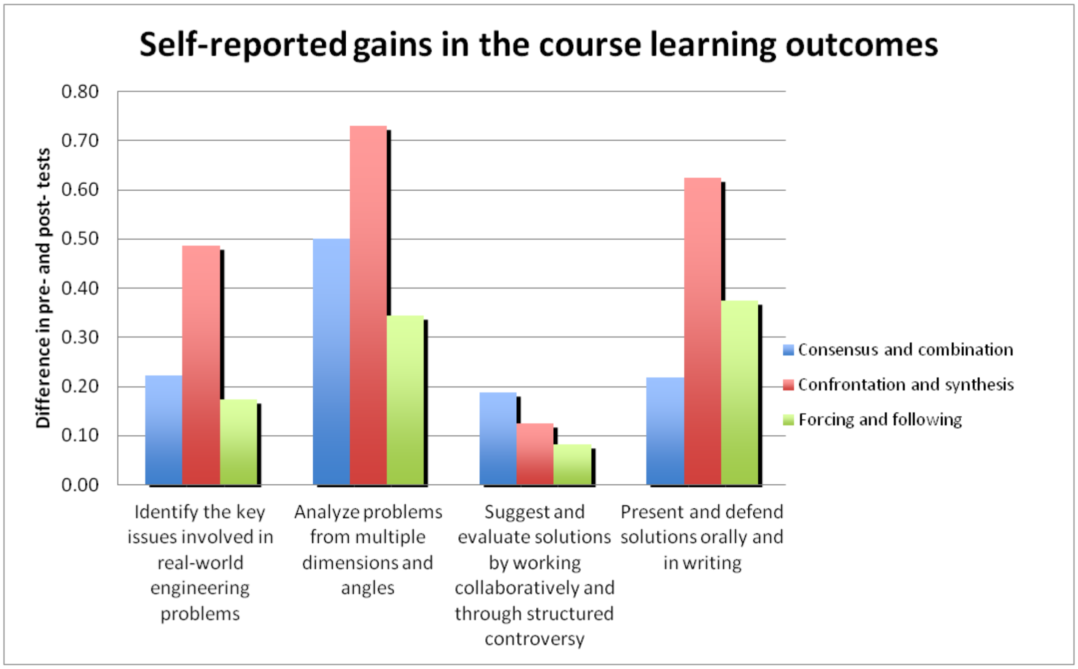

Figure 3 Self-reported gains in the learning outcomes (on a scale of 1-5, 1 means needs work, 3 means competent and 5 means exemplary; the gains were the differences between the post-test and pre-test.)

A similar pattern was observed in students' self and peer assessment of the collaborative problem solving processes based on the rubric. Teams using "consensus and combination" style rated themselves and their counter-team higher in almost every item in the rubric except the critical thinking. Figure 4 shows the average rating given by students after the constructive controversy and before the release of the report scores.

Discussion

Student teams approached constructive controversy in different ways. Their learning outcomes were also affected by the style adopted. Student teams under the "confrontation and synthesis" discussion condition produced the best results among all teams despite the fact that their average scores in the first report before the constructive controversy were below average among all. These two teams out-performed the others not only in terms of the integrated solutions they generated, but also the self-assessment scores in their learning gains, as well as their abilities to articulate the essence of constructive controversy during focus groups.

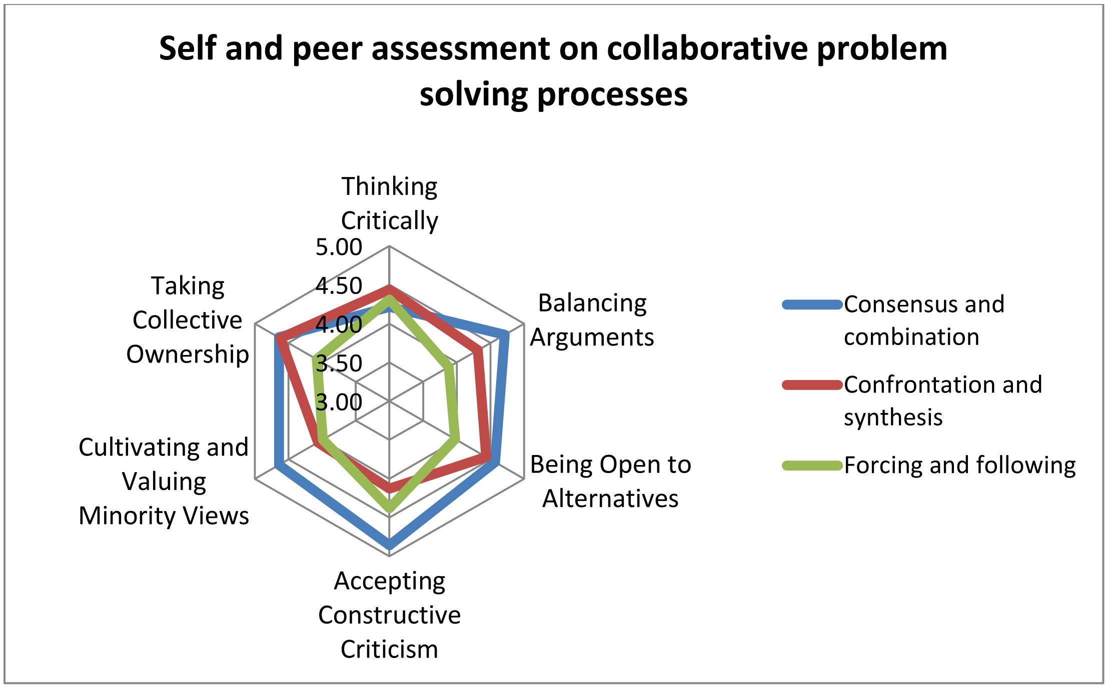

Figure 4 Students' self and peer assessment of collaborative problem solving processes (on a scale of 1-5, 1 means needs work, 3 means competent and 5 means exemplary)

"Consensus and combination" condition did not generate a promising result in terms of the final integrated solution since the aspect of "critical linking" was lacking. Although this pair of teams remained above average in both report scores, the gap between their average scores and scores of weaker teams was shrinking. However, this approach seemed to generate the best inter-team relationship since "harmonious relationship" was appraised by these teams but not the others according to their written comments. Furthermore, "consensus and combination" generated the highest peer assessment scores on collaborative problem solving, which meant that team members perceived each other as doing well in the collaborative problem solving processes.

"Forcing and following" produced the lowest score on the integrated solution. The self-reported learning gains were not as many as the other teams. One needs to note that many factors interacted and affected the final results, for example, lack of commitment in Team G, so the undesirable results may not be simply due to the approach in constructive controversy. Nevertheless, "forcing and following" resulted in dissatisfaction about inter-team relationship as reflected in the focus group and peer assessment scores.

The overall pattern is consistent with the literature, particularly, that constructive controversy produced higher level cognitive processing than the concurrence-seeking group (Smith et al., 1984). A better integrated solution to a complex and ill-structured problem could be reasonably viewed as a reflection of higher level cognitive processing. The results in this study also indicated that "controversy" did not necessarily lead to harm in the inter-team relationship, which has been shown in the study of Smith and his associates. Even though teams using "confrontation and synthesis" did not rate them the highest in the collaborative problem solving process, their ratings were still relatively high on a 5-point scale. Meanwhile, teams using "consensus and combination" rated their collaborative problem solving surprisingly high, which may reflect that harmonious relationship was indeed highly valued by students in Hong Kong and that the perceived good relationship led to the higher rating of the cooperative process. In other words, students' perceptions of relationship could affect their judgment on the process and skills.

With a small-scale implementation of constructive controversy in the course on grand challenges in only one semester, this case study by no means aims to conclude the effectiveness of constructive controversy compared to other pedagogies, as has already been appropriately done in literature. Instead, this study describes three different ways to constructive controversy adopted by student teams and different learning outcomes as a result. This study hopes to raise the issue that the learning outcomes could be very different if students take different approaches to the constructive controversy process. A validation of the framework is needed in future semesters and other contexts.

Implications

One thing that set Teams C and D apart from the other teams was the high performance of their peer tutors, who were able to explain the principles, set out the plan, and monitor each team in the constructive controversy process. Not every peer tutor could perform the roles and responsibilities as assigned. Another issue observed was that the lack of active listening skills could inhibit the effectiveness of constructive controversy. Many students were not able to listen carefully and actively, or ask critical questions. Most of the critiques they provided after listening to the other team's solution were on clarification of facts, for example, sources of data, accuracy of the formula, but not on the assumptions underlying the propositions others stated. Lack of such skill limited students' abilities to practice constructive controversy. Further training on this aspect and a rehearsal or practice on generating counter-arguments and rebuttals would be necessary.

Further improvement could therefore be realized through a proper training and continuous feedback to both students and peer tutors on the constructive controversy process. The training and monitoring of peer tutors is another challenge. It would be useful to collect feedback from students and provide formative assessment to peer tutors at some critical points, for example the time before the integration of solutions between two teams. The findings of this study could be conveyed to students and their peer tutors as part of the training so that they would be aware of some inappropriate situations, for example, no "conflicts" in Teams A and B, and too many affective conflicts in Teams E and F, and Teams G and H. This could be supported through peer counseling or peer supervision.

Conclusions

Constructive controversy has and can be used in classrooms with a variety of structures to help students learn about any topic or issue that has multiple perspectives and an overall goal of striving for agreement or at least agreeing on the best arguments on all sides. However, compared to other forms of cooperative learning (cooperative jigsaw, cooperative problem-based learning, cooperative tests), the extent of adoption and implementation is very low. The conceptual cooperative learning model (positive interdependence, individual and group accountability, face-to-face promotive interaction, teamwork skills, and group processing) is complicated and requires dedication and practice to implement effectively. Explicitly adding the controversy and conflict dimension appears to create a barrier for many instructors. Effectively implementing constructive controversy requires instructor professional development, instructor support, and congruent instructional leadership. There are several guides available for constructive controversy and other cooperative learning strategies, and there are some workshops and training sessions available. Empirical evidence shows the benefits of constructive controversy to students. We argue that constructive controversy has excellent potential for preparing students with the skills and confidence to productively engage in discussions of complex and contentious issues, and to foster the emergence of innovative and creative ideas.

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Further Material from the ASEE/IEEE Frontiers in Education Conference 2009 San Antonio, TX

- Special Session: Constructive Academic Controversy: The Art of Arguing to Enhance Learning

- Session Description [http://www.ce.umn.edu/~smith/docs/Matusovich-Smith-FIE2009-Special%20Session.pdf
- Supporting Paper [http://www.ce.umn.edu/~smith/docs/Matusovich-Smith-Constructive_Academic_Controversy-FIE2009.pdf]Slides [http://www.ce.umn.edu/~smith/docs/Matusovich-Smith-FIE2009-controversy-10_15-2.pptx]
  - Session Handout [http://www.ce.umn.edu/~smith/docs/Matusovich-Smith-FIE2009-one page handout-2.ppt]
  - Pro Position Handout [http://www.ce.umn.edu/~smith/docs/Yes ABET defines engineering.ppt]
  - Con Position Handout [http://www.ce.umn.edu/~smith/docs/No ABET doesn't define engineering.ppt]