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Design Fixation and Cooperative Learning in Elementary Engineering Design Project: A Case Study

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Abstract

This paper presents a case study examining 3rd, 4th and 5th graders' design fixation and cooperative learning in an engineering design project. A mixed methods instrument, the Cooperative Learning Observation Protocol (CLOP), was adapted to record frequency and class observation on cooperative learning engagement through detailed field notes. Students' design journals and reflections were also analyzed for an inductive qualitative analysis. The findings indicate three major themes of design fixation: 1) fixation on common features of things; 2) fixation on popular teenage culture; 3) fixation on the first design idea. In the cooperative learning process of elementary engineering design project, although pupils had demonstrated some abilities to solve concrete problems in a logical fashion, the participants encountered a number of obstacles in the group. Dominance, social loafing, and other problems occurring in the group process might have offset certain benefits of cooperative learning. Implications of the findings are also discussed.

Keywords: Engineering design, Fixation, Cooperative learning, Elementary students, Case study.

Introduction

An important national trend in the United States is the profound inadequacies in K-12 science, mathematics, and engineering education (The National Science Board, 2003). Engineering connects math and science concepts to real-world experiences in an enjoyable way and it enables children to design and innovate things in their daily life. (Iversen, Kalyandurg & Lapeyrouse, n.d.). To this end, incorporating curricula in engineering design in elementary schools can help address American students' deficiencies in math and science achievements, and can potentially increase the pool of engineering and science specialists in the U.S. by exposing technical career opportunities to students at an earlier age (Crawford, Wood, Fowler & Norrell, 1994). As teams are essential for developing engineering competencies (Tribus, 1993), this case study focuses on the design ideas generated by 3rd-5th grade elementary school students when they adopt cooperative learning strategies in an engineering design project.

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Generating ideas at an early stage plays an important role in engineering design and thus the ability to creatively generate novel and purposeful ideas is a necessary part of solving design problems (Nicholl & McLellan, 2007). Unfortunately in the design process prior knowledge can constrain creative thinking and results in fixation, which is “a blind, and sometimes counterproductive, adherence to a limited set of ideas in the design process (Jansson & Smith, 1991, p. 4).” Smith (1995) also mentioned solving a problem is a normative cognitive process in which an individual plans a route to get to a destination. He argued when the individual does not know about a particular knowledge or technique, he meets the obstacle in the route, which ultimately leads the individual to be fixated. As elementary school students have limited prior knowledge in engineering, they are likely to encounter fixation. They would tend to use the knowledge that readily comes to their mind during the design process.

On the other hand, cooperative learning encourages students to work in groups to accomplish a common goal (Johnson, Johnson & Smith, 2006). Young learners are inherently active to investigate and share with others what they have found out (Tanner, 1997). When a child is at the end of preoperational period of cognitive development (about the age of 6 or 7) most children are able to accommodate the views of others (Wadsworth, 1971) and Piaget believed peer interactions are critical to helping children get rid of egocentric thought (Driscoll, 2005). Although aspects of Piaget’s theory were not agreed by some theorists, such as the aspect of egocentrism in young children, Piagetian framework was generally accepted (O'loughlin, 1992). Therefore based on Piaget’s theory introducing cooperative learning to elementary engineering design projects is in line with the cognitive development of children. As cooperative learning arrangements lead to students’ more frequent generation of new ideas and solutions and ultimately promote development of higher-level reasoning and critical thinking (Johnson and Johnson, 1989; Johnson, Johnson & Holubec, 1998), this case study focuses on studying the cooperative learning in an elementary engineering design projects.

Despite that there is plenty of literature on design fixation and cooperative learning respectively, as engineering is typically not included in elementary school curriculum in the U.S., there is very limited amount of existing research on students’ design fixation or cooperative learning in elementary engineering design projects. This is where this case study hopes to make a contribution and add to what is already known.

The purpose of this study is to provide insight into an elementary engineering design project and ultimately help engineering educators to improve instructional design. The research questions are: 1) What does design fixation look like in elementary engineering education? 2) How do elementary students perform in group in a cooperative engineering design project?

Literature review

Engineering design process for children

Engineering education should emphasize engineering design process (Cunningham & Hester, 2007; Katehi, Pearson & Feder, 2009). Engineering design refers to an engineer’s approach to identifying and solving a problem, which is “(1) highly iterative; (2) open to the idea that a problem may have many possible solutions; (3) a meaningful context for learning scientific, mathematical and technological concepts; and (4) a stimulus to systems thinking, modeling, and analysis (Katehi et al., 2009, p. 151).” Children have innate enthusiasm toward creating thinking, taking things apart, and figuring out how things work (Cunningham, 2009). A five-step engineering design process model for children consisting of Ask, Imagine, Plan, Create, and Improve was developed by Engineering is Elementary (EiE) program, a national program which created elementary-level engineering units based on national science education standards. The engineering design process and the questions to be asked in each step are illustrated in the following figure:

ASK
What is the problem?
What have others done?
What are the constraints?
IMAGINE
What are some solutions?
Brainstorm ideas.
Choose the best one.
PLAN
Draw a diagram.
Make lists of materials you will need.
CREATE
Follow your plan and create it.
Test it out!
IMPROVE
Talk about what works, what doesn't, and what could work better.
Modify your design to make it better.
Test it out!

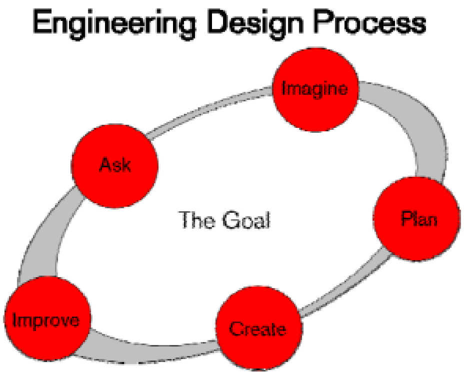

Figure 1. The Design Process developed by EiE Program (Cunningham & Hester, 2007, p. 5)

Cooperative learning strategies

Cooperative learning involves students' working together in groups to accomplish learning tasks or master subject matter content. It is a structured process in which students are actively engaged in learning activities in groups and rewarded based on group performance (Slavin, 1980). Cooperative learning includes the following five elements (Johnson, Johnson & Smith, 2006): 1) Positive interdependence: group members rely on one another to achieve the goal. Everyone suffers the consequences if any group member fails to complete their task; 2) Individual accountability: all group members are held accountable for doing their share of the work; 3) Face-to-face promotive interaction: although some of the group work may be done individually, some must be done interactively; 4) Interpersonal and small group skills: students are to develop and practice trust-building, decision-making, communication and conflict management skills; 5) Group processing: group members set group goals together, periodically reflect on what they are doing well as a team and identify improvements they need to make to work more effectively in the future.

A large amount of empirical evidence shows that cooperative learning significantly increases academic performance, achievement and has positive effects on social constructs such as peer relations and self-esteem (Johnson, Johnson & Holubec, 1998; Johnson, Johnson & Smith, 1998; Williamson & Rowe, 2002; Salkind & Rasmussen, 2008). Cognitive elaboration perspectives claim that cooperative learning enhances students' learning outcomes by involving more restructuring and elaboration when students try to explain the material to someone else. Table 1 demonstrates several cooperative learning strategies.

Table 1. *Cooperative learning strategies*

CL Strategies	Description
Think-Pair-Share (Hassard,1996)	This is a procedure where students consider a question individually, discuss their ideas with another student to form a consensus answer, and then share their results with the entire class.
The Jig Saw method (Aronson, Blaney, Stephin, Sikes, & Snapp, 1978)	Students become "experts" on a concept and are responsible for teaching it to the other group members. Groups subdivide a topic and members work together with those from other groups who have the same topic. They then return to original groups and explain the topic.
Jigsaw II (Slavin 1986)	This is an adaption of The Jigsaw method in which individual scores are combined at the end in some manner to yield a team score.
The Student Teams-Achievement-Divisions (STAD) (Slavin, 1990)	The teacher presents a lesson, and then students work within their teams to complete a set of worksheets on the lesson and make sure that all team members have mastered the lesson. Finally each student then takes a quiz on the material and the scores the students contribute to their teams are based upon the degree to which they have improved their individual past averages.
TGT (Teams-Games-Tournaments) (DeVries & Slavin, 1978)	This method is related to STAD and instead of taking quizzes the students play academic games as representatives of their teams. They compete with students having similar achievement levels and coach each other prior to the games to insure all group members are competent in the subject matter.
Learning Together (Johnson & Johnson, 1987)	This model involves students working in four- or five-member heterogeneous groups on assignments. The groups hand in a single completed assignment and receive praise and rewards based on the group product. Students are also evaluated individually.
Coop-Coop (Kagan, 1985)	Teams of students choose topics for study and then break them into subtopics. Each individual is responsible for learning and teaching about a subtopic. The team then makes a presentation on the topic to the whole class.
Group Investigation (Sharan & Sharan, 1992)	Students form their own two- to six-member groups. After choosing subtopics from a unit that the entire class is studying, the groups break their subtopics into individual tasks and carry out the activities that are necessary to prepare group reports. Each group then makes a presentation or display to communicate its findings to the entire class.

Fixation & cooperative learning in K-12 engineering design

Fixation is the result of everyday thinking being limited by a fixed set of ideas (Cunningham & Hester, 2007). Design fixation is a common phenomenon among both inexperienced and experienced designers (Lindsey, Tseng, Fu, Cagan, Wood, & Schunn, 2010). Existing knowledge can influence the generation of new ideas and this process is referred to as 'structured imagination'—"the fact that when people use their imagination to develop new ideas, those ideas are heavily structured in predictable ways by the properties of existing categories and concepts (Ward, 1995, p. 157)." Showing example solutions also can reduce the design solutions generated by a designer, and designer's solutions will have certain aspects of the example solution (Jansson & Smith, 1991; Purcell & Gero, 1996). Lindsey et. al.'s (2010) study compared a control group whom were provided with an example solution with a defixation group whom were given an example solution along with a number of alternative solutions and materials to mitigate their design fixation. They found out the design fixation could be mitigated through providing the participants with defixation instruction. In terms of K-12 students, Nicholl & McLellan (2007) carried out a study to examine how fixation applied to the idea generation process when pupils were solving design and technology problems. The study indicated fixation was popular among the 11-16 year old pupils. Pupils' stereotypical design ideas predominantly reflected popular teenage culture and gender patterns. The study also pointed out that pupils often felt annoyed that they were asked to think of multiple ideas when they knew what they wanted to do right away. Pupils in the study tended to stick to their first design idea, which often turned out to be stereotypical design ideas. In terms of the intervention strategy, McLellan & Nicholl' (2011) argued as teachers' product analysis could lead to design fixation, teachers should select appropriate ways to introduce the design task in order to balance the explicitness and ambiguity, for example, teachers can show a different product in the beginning to make the task more open-ended.

As mentioned in the above engineering design process, in the first and second steps of Ask and Imagine, students need to consider about the questions like "What is the problem? What are some solutions?" When brainstorming ideas and choosing the best one, student needs to explain his or her ideas to peers and negotiate with them to locate the best alternative. According to the cognitive elaboration perspective (Slavin, 1996), this process would probably deepen students' understanding of the engineering design problem and accordingly improve their decision making as a group. Indeed the majority of Engineering is Elementary design activities are done in small groups, which can encourage students to generate a variety of ideas or solutions to develop the product with their group members (Cunningham & Hester, 2007).

Research methodology

Overview of design: A case study

As this research was intended to explore what design fixation looks like in elementary engineering education as well as how elementary school students perform in a cooperative engineering design project, a case study focusing on one elementary engineering design project was conducted in order to arrive at an in-depth description and understanding of the entity (Ary, Jacobs, Sorensen & Razavieh, 2006; Patton, 2002). The embedded design looking for consistent patterns of evidence across multiple units of analysis within the case (Yin, 1994) was adopted. The units of analysis included individual elementary school students, three different grade levels (3rd, 4th & 5th), and 12 cooperative learning groups (four groups per grade level).

Research setting and participants

An elementary engineering design project involving a group of 3rd, 4th and 5th graders was selected as the case study. The project was part of a pull-out engineering program carried out in a Midwestern private elementary school. The nine-week pull-out engineering program was conducted every Tuesday and Friday mornings. Within this program there was an engineering design project involving a 3-day design circle: ask and imagine; start to plan (day 1); plan and create the prototype (day 2); present the final product to clients and answer their questions (day 3). 41 students in total participated in this study, which included 12 third graders (6 boys and 6 girls), 14 fourth graders (5 boys and 9 girls), and 15 fifth graders (7 boys and 8 girls).

The students worked with their teammates in the engineering class in two-, three- and four-member groups on the group design assignment: using duct tape to design and create a wallet, a tote bag, a water bottle holder, or a school folder. This design challenge was created by the instructor, who was a doctoral student majoring in engineering education and gifted education. The instructor had more than five years of elementary school teaching experience and was experienced in P-12 engineering teacher professional development. The instructor introduced the design challenge to the students without the aid of any examples and was intended not to provide any unnecessary information that might influence the students' behavior. It should be mentioned when the instructor briefed the challenge, a tote bag behind the teacher's desk might have been seen by the students. This study focused on the first two days of this project, during when the pupils were asked to come up with four individual design ideas first, then they chose one to be their best idea to share with the whole group. After that the group decided on one group design idea.

Instruments and data collection

As a case study, triangulation was done with multiple data sources (Yin, 1984): 1) Documents--students' design journals recording the individual designs as well as their selected final group design; students' reflections on their individual design idea generation and group design selection; instructional materials; 2) Classroom observation.

In order to systematically observe elementary students' behavior in the group engineering design project, the validated Cooperative Learning Observation Protocol (CLOP) (Kern, Moore & Akillioglu, 2007) was adapted for evaluating the elements of cooperative learning and teaming in an engineering setting to guide the observation. The CLOP is a useful mixed methods instrument recording frequency and evaluations of observed instances of cooperative learning engagement through detailed field notes (Kern et. al., 2007). The adapted CLOP was reviewed by the instructor of the elementary engineering design project to ensure its appropriateness for classroom observation. After incorporating the instructor's comments, the CLOP was used to rate participants' behavior in terms of the five corresponding elements of cooperative learning identified by Johnson, Johnson & Smith (2006): positive interdependence (P), individual accountability (I), group processing (G), social skills (S) and promotive interaction (F). Each item was allocated 10 points with the higher total score indicating a higher level of collaboration and effectiveness in cooperative learning. Observation notes were also recorded with the ratings.

The data were collected from the first day of the design project in class. At the beginning of the project, the students of each grade were divided randomly into 4 groups by the instructor and they were given roughly 15 minutes to complete their individual design journals and another 15 minutes for group discussion. The students were informed that their group design would be judged according to the following rubric: 1) Task completion (Did the team meet the task specifications? 2) Attractiveness (Would this item appeal to the public?) 3) Creativity (Was the team creative in their design?) 4) Functionality (Is the team's design functional? Can the user actually use it?) The instructor also told the students that the team with the highest score based on the above rubric would be awarded certificates for their winning design.

Role of the author

This paper is developed from a research course project. The author of this paper worked with her fellow graduate students in an advanced research methods class to come up with the overall research topic, design the methodology and select the instruments. Four of the author's fellow classmates, who were skilled in educational research, were assigned to travel to the site for conducting classroom observation using the CLOP instrument and collecting various data artifacts. The author then came up with her own specific research questions and selected relevant data to conduct data analyses and wrote up this research paper.

Results

In this study, data were analyzed through content analysis and descriptive statistical analysis. Content analysis is broadly defined as “any technique for making inferences by objectively and systematically identifying specified characteristics of messages" (Holsti, 1969, p. 14), so the researchers applied it to analyzing participants’ design journals and the field notes of class observation. Emergent and priori coding (Stemler, 2001), categorizing of the data (Weber, 1990) were utilized to describe what design fixation looks like and recognize its patterns among the participants.

Three major themes of design fixation among pupils

Elementary school students were asked a series of questions in relation to both their individual designs and group design in the reflection: After you imagined, you choose which idea to share with the group? Why did you choose this idea? Where did you get your ideas when you were imagining your designs? Students’ answers in the reflections were examined together with the classroom observation data on design idea generation process. The data suggested that evidence of fixation was common in the elementary engineering design project though it appeared in a number of forms. The content analysis identified the following major themes of design fixation among pupils: 1) fixation on common features of things; 2) fixation on popular teenage culture; 3) fixation on the first design idea.

Fixation on common features of things. Elementary school students tended to come up with their design solutions based on commonly seen features of certain things. For example, when designing a wallet, the predominantly majority of students chose the most common shape of rectangular to be their main shape, rather than trying some more unique shapes such as circle, triangle or crescent. Moreover, 34% of the participants in the study did not explicitly explain where they got their ideas in the imagination process. Some quotations of students’ responses in the reflections are “I got my ideas from my brain”; “In my head about a folder”; “when I see bags I think that.” Some fifth graders attempted to give more reasonable but still somehow vague answers: “I saw something and changed it a little. I also thought about the constraint”; “From recent events.”

Fixation on popular teenage culture. Elementary school students’ design ideas also reflected popular teenage culture. The following are some quotations of students’ answers to the sources of their design ideas: “From Justin Biebers birthday”; “Lady Gaga because I thought out of the box in design and technique”. Some of their design ideas also reflected gender stereotypes. Girls’ designs tented to be more decorated such as using heart-shape, drawing flower patterns, emphasizing the use of colors; and adding straps/handles to the wallet design. For example, two girls mentioned that “I like the shape of the flower and when I was drawing the roses”; “I came up with this because I love flowers and I like we made it the colors of the flowers”. One girl explicitly mentioned in the reflection that she got the idea from “Vera Bradley totes,” which is a feminine brand.

Fixation on the first design idea. As aforementioned, each student was asked to choose one of their four individual design ideas to be the best idea, which would then be shared with their group. As demonstrated in Figure 2, according to students’ individual design journals, the first design idea was chosen to be participants’ favorite picture to share with the group members for 14 times, which was the most frequently chosen one out of the four design ideas. The second, third and fourth design ideas were chosen 11, 6, and 10 times respectively. The typical reason given by participants to choose the first design idea is "I chose that idea because it looked easiest."

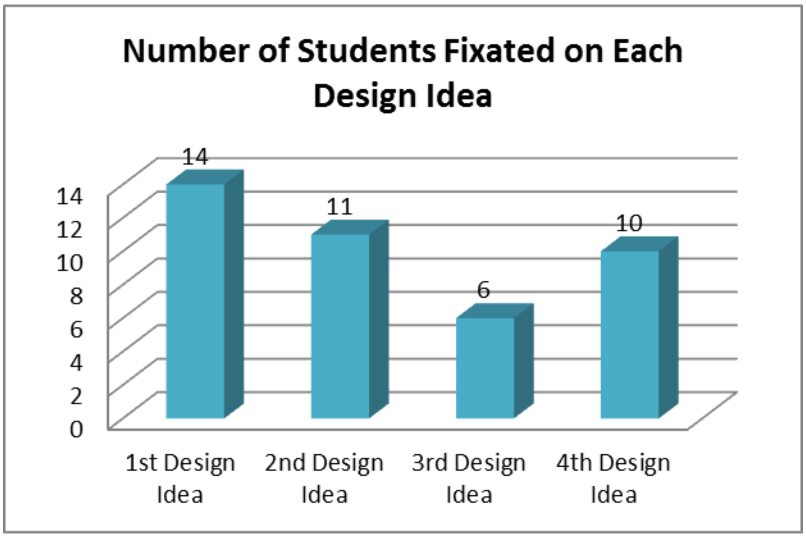

Figure 2. Number of students fixated on each design idea

The cooperative learning scores based on CLOP

Table 2 below demonstrates each group's mean score of the cooperative designing of engineering products based on the CLOP instrument. The highest mean among the five cooperative learning elements is individual accountability (Mean I= 6.33) while the lowest mean is promotive interaction (Mean F= 5.88).

Table 2. *Cooperative learning score based on CLOP*

		Positive Interdependence (P)	Indvidual Accountability (I)	Group Processing (G)	Promotive Interaction (F)	Social Skills (S)
3rd Grade	Group 1 Mean	5.00	5.00	6.00	4.00	4.50
	Group 2 Mean	4.50	4.00	4.00	7.00	6.00
	Group 3 Mean	4.00	5.50	4.00	6.00	6.00
	Group 4 Mean	7.50	8.00	8.00	6.50	6.00
4th Grade	Group 1 Mean	7.00	6.50	6.00	6.50	6.50
	Group 2 Mean	7.50	7.00	6.00	4.00	6.50
	Group 3 Mean	5.50	6.00	8.00	8.00	7.00
	Group 4 Mean	6.00	7.50	4.50	5.00	4.00

Table 2 (Cont.). *Cooperative learning score based on CLOP*

		Positive Interdependence (P)	Indvidual Accountability (I)	Group Processing (G)	Promotive Interaction (F)	Social Skills (S)
5th Grade	Group 1 Mean	4.50	5.50	5.00	4.00	5.50
	Group 2 Mean	9.00	8.50	9.00	8.50	9.50
	Group 3 Mean	6.50	7.00	5.50	6.50	6.50
	Group 4 Mean	5.00	5.50	7.00	4.50	5.00
Mean		6.00	6.33	6.08	5.88	6.08
Standard Deviation		1.52	1.32	1.64	1.57	1.40

Discussion

This case study indicated that many pupils failed to generate novel ideas in engineering design project and fixation was evident. As mentioned in the literature review, when an individual does not know about a particular knowledge or technique, he or she is likely to be fixated (Smith, 1995). Pupils often have limited prior knowledge, this may explain why pupils tended to fixate on the common features of things or the ideas that first came to their mind. On the other hand, according to Jansson & Smith (1991), prior knowledge is essential in the design process as designers can think of new ideas on the basis of what they have already known; thus it should be noted design fixation needs to be viewed differently from the designer's prior knowledge scope. Design fixation "should probably be seen only as that which prevents the consideration of all of the relevant knowledge and experience which should be brought to bear on any given problem" (p. 10). The common reliance on their personal items to generate design solutions among pupils may also be explained by Ward, Patterson, Sifonis, Dodds, & Saunders's (2002) path-of-least resistance model in the idea generation, which means the majority of people utilize the items that come to their mind more quickly as the sources for developing new ideas.

The findings from this study conform to the arguments made by Nicholl & McLellan (2007). Nicholl & McLellan argued that design fixation is the result of the subconscious, automatic and normative cognitive processes of pupils. Participants in this study showed a tendency to generate the design solutions with little self-awareness. They just vaguely knew something popped up in their head to work as the source of design solution. Besides this study also indicated pupils relied on the teenage culture that they attached to the most to derive design ideas, which is in line with Nicholl & McLellan's finding that design idea generation clearly reflects the hobbies and interests of pupils of certain age groups.

In terms of cooperative learning, the pupils in this study were informed at the beginning of this engineering design project that they would work in groups to compete in a design competition. They would present their final products to the "clients" and be awarded a certificate if they win. This instructional design stimulated the individual accountability (Mean I= 6.33, *sd*=1.32). The pupils expected each other's participation in the group work. For instance, at the beginning of the project, most groups brainstormed on which one of the four products they would like to do and then voted; and they constantly checked each other's progress when generating individual design solutions. Kern et. al. (2007) argued social skills (Mean S= 6.08, *sd*=1.40) contributing to cooperative learning include asking clarification, praising, paraphrasing, mediating conflicts and so on. The pupils in this study evidenced a number of such skills. For example, the pupils gave feedback to each other like "It's a good/cool idea"; "I like it"; "Isn't it so shiny, we did a good job" and so on. They asked their group members for clarification such as the size requirement of the product or their work progress. When they had divergences such as the color or size selection, they negotiated through conversations. These observations are in line with the literature review that the group work can encourage students to generate more solutions in engineering design activities.

Meanwhile several problems had been observed in the cooperative learning process. Some dominant or most capable members of a group took over leadership roles at the expense of others. For instance, one pupil boasted "I'm the best fashion designer in Indianapolis and I guarantee it." On the other hand, the introverted or the less capable pupils withdrew from group discussion and this can be identified as social matching, which is a tendency to conform to peers (Asch, 1951). As the design responsibility is shared among the group members, some other pupils took the advantage of group work without working to their full potential, which was referred to as social loafing (Latane´, Williams & Harkins, 1979). These problems were likely to reduce the engagement and cohesiveness among the group in cooperative learning. This may explain why the element of positive interdependence had a relatively lower score in this study (Mean P= 6.00, *sd*= 1.52).

The 7-to11-year-old participants in this study belong to the concrete operational period (Driscoll, 2005), during when children overcome egocentrism and demonstrate logically integrated thoughts to solve concrete problems; however, they were unable to solve problems systematically or constantly reflect the group process. When finishing drawing their individual design solutions, several groups chose to make in-group presentations, nevertheless due to the above mentioned problems such as dominance, social loafing and social matching, group members did not receive much constructive feedback from their peers. These problems might have offset certain benefits of cooperative learning and even led to more fixation. For example, there were a couple of groups who fixed on one member's design idea and finally chose it as their group design solution without making any additional changes.

Conclusion

In this case study, design fixation was shown to be rife and predictable among pupils, who largely fixated on their prior knowledge of certain things and the teenage culture when designing engineering products. In the cooperative learning process of this elementary engineering design project, although pupils had demonstrated some abilities to solve concrete problems in a logical fashion, the 3rd, 4th and 5th graders encountered a number of obstacles in the group. For improving the results of cooperative learning, this case study suggests incorporating an instruction that aims at encouraging students' interaction in the group work. Instructors may establish clearly defined rules and criteria for grading individual contribution to the group work and incorporate some non-competitive, cooperative games which would enhance pupils' social skills in class. For example, they can adopt some role-play games in which pupils' skills in solving conflicts, decision making, consulting others, making observations and so on could be fostered.

This study sheds light on the understanding of design fixation in a cooperative elementary engineering design project. Meanwhile it should be noted that generalizability is a limitation associated with this study as the engineering design project was carried out among a sample of 41 pupils of 3rd, 4th and 5th grades and it was about designing four objects specifically: wallet, water bottle holder, school folder and tote bag. The design of these objects are subject to possible socially fixated concepts as the students can easily see these objects in their everyday life. In the future, research on a variety of design projects encouraging more open and risky design challenges could be studied in elementary classrooms. With a larger sample size, further research could be carried out to quantitatively measure the effects of cooperative learning on elementary students' design fixation.

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