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► To cite this version:

Behiye Ubuz, Yurdagül Aydınyer. Engineering design process on designing a neighborhood in project-based learning environment: a comparison of field dependent and field independent cognitive style students. Thirteenth Congress of the European Society for Research in Mathematics Education (CERME13), Alfréd Rényi Institute of Mathematics; Eötvös Loránd University of Budapest, Jul 2023, Budapest, Hungary. hal-04420569

HAL Id: hal-04420569

<https://hal.science/hal-04420569>

Submitted on 26 Jan 2024

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Engineering design process on designing a neighborhood in project-based learning environment: a comparison of field dependent and field independent cognitive style students

Behiye Ubuz¹ and Yurdagül Aydınyer²

¹Middle East Technical University, Faculty of Education, Ankara, Turkey; ubuz@metu.edu.tr

²Maltepe University, Faculty of Education, Istanbul, Turkey

In this paper we explore 7th grade field dependent, field mixed and field independent cognitive style students' engagement with engineering design processes while designing a two-dimensional scale plan of a neighborhood in Project Based Learning environment. To do this, verbal protocols throughout classroom observations and interviews were collected from 97 seventh-grade students. We analyze these protocols to document the students' engagement with engineering design processes. The results show that project-based learning engages all students in engineering design processes while designing a two-dimensional scale plan of a neighborhood as a project.

Keywords: Cognitive style, engineering design process, geometry, project-based learning.

Introduction

The project-based learning (PBL) approach engages students actively in pursuing solutions to authentic (driving) question that serves to organize and guide instructional tasks in both the presentation (benchmark lessons) and practice of selected topics (project) (see Ubuz & Erdogan, 2019 for the definition of presentation and practice of selected topics). PBL scaffold learning and build meaningfully powerful Science, Technology, Engineering, and Mathematics (STEM) concepts supported by language, social studies, and art (Capraro & Slough, 2013). PBL builds on engineering design process as the cornerstone (Capraro & Slough, 2013). The key features of PBL (e.g., Markham, Larmer, & Ravitz, 2003) are to encourage different students' learning (see Ubuz & Aydınyer, 2019) and develop the essential knowledge and skills to engineer a personalized solution to the design problem (see Ubuz & Aydınyer, 2022). Ubuz and Aydınyer (2019) reported that the field dependent (FD)s, field mixed (FM)s, and field independent (FI)s achieved a statistically significant, similar, and large mean increase for all measures regarding to the geometry knowledge and attitude toward geometry but their increase for all measures were not significantly different in the PBL environment in which a two-dimensional scale plan of a neighborhood was designed. Contextualizing, visualizing, and collaborating opportunities in the PBL environment seemed to accommodate the needs of students with different cognitive styles. Ubuz and Aydınyer (2022) another study has proven that designing a two-dimensional scale plan of a neighborhood in the PBL environment engages students in engineering design process (EDP) and in turn probably deepen their EDP capabilities. This result is expected considering the structured PBL environment developed according to the key features of PBL. Our current research extends these two previous studies (Ubuz & Aydınyer, 2019, 2022) to investigate FDs, FMs, and FIs cognitive style students' engagement with engineering design processes while designing a two-dimensional scale plan of a

neighborhood in PBL environment. Field Dependence–Independence (FDI) construct, introduced by Witkin, Oltman, Raskin, and Karp (1971) when they developed the Hidden Figures Test, is a widely studied dimension of cognitive styles that is based on individual’s tendency of perception of the surroundings and provides information on cognitive restructuring and social behaviors (Saracho, 2003).

This paper is guided by the following research question: How do FD/FM/FI cognitive style students engage with the EDP in the PBL environment? EDP model followed in the current paper is composed of the following four characteristics: 1) Defining the problem, 2) generating and selecting between multiple possible solutions, 3) modeling and analysis, and 4) iteration (Berland, Steingut, & Ko, 2014). This current study shows differences and similarities in design behavior for individual students that solved the problems as FDs, FM, or FIs. By understanding the way that different cognitive style students practise design we can learn how different students practice design. This study also opens the way to conduct further research about EDP and cognitive style or any other individual differences.

Methods

Participants

The participants in the present study included those students for whom Project Based Geometry Learning (see Ubuz & Aydinyer, 2019) were instructed for five 40-min periods per week over the course of six weeks (altogether thirty 40-min periods). A total of 97 seventh-grade students in three intact classes from a private school in Ankara were classified as FD, FM, or FI as a result of their performance on the Group Embedded Figures Test (GEFT) (Witkin et al. 1971). The grouping of the participants was based upon the mean score and the standard deviation of the GEFT (see Table 1). Students who achieved one half standard deviation below the mean were considered to be FD; those located one half standard deviation above were classified as FI; and those in the middle were classified as FM.

Table 1: Mean, standard deviation, and range of the three cognitive style groups based on the Group Embedded Figures Test and the three cognitive style groups in each class

Group	<i>Class A</i>	<i>Class B</i>	<i>Class C</i>	<i>N</i>	<i>M</i>	<i>SD</i>	Range
FD	10	9	12	31	2.84	1.81	0–5
FM	14	10	11	35	8.03	1.54	6–10
FI	8	13	10	31	13.84	2.13	11–18
Total	32	32	33	97	8.23	4.78	0–18

Note. FD = field dependent; FM = field mixed; FI = field independent.

Description of the project in Project-Based Learning Environment

In the PBL environment, students faced a challenging project, including the following problem situation to specify the well-defined outcome and ill-defined task:

“There is a so-called contest entitled Neighborhood Renewal Project for redesigning a neighborhood replacing old buildings (not historical ones) with new ones. When you begin to design your scale plan, keep in mind that you have some design requirements.”

The project was conducted during the last 14 lesson hours. To mirror real-world engineering, the students had to accommodate the following requirements to design their scale plan:

- Designing a two-dimensional scale plan of a neighborhood located on a rectangular smooth surface with actual dimensions of 120 m and 170 m on an empty white cardboard with the corresponding dimensions of 48 cm and 68 cm.
- Considering the needs of the residents and environmental problems encountered by them.
- Including different positions of three lines in a plane representing roads as well as certain polygons with some dimensions representing ground areas covered by buildings and other areas.

Students were expected to design their scale plan mainly using their knowledge of geometry and mathematics. The students were assigned to small groups composing three or mostly four students on the basis of the data from GEFT. Each group included at least one student from each cognitive style. Once the problem, “How do you design your neighborhood plan?”, was posed to the class at the beginning of the PBL, some sample scale plans of different neighborhoods projected on a large screen were discussed in regard to the positions of the roads with respect to each other and the types of polygons used for buildings based on their existing knowledge. Then, they were asked to conduct some preliminary research to design their plan, including:

- Finding some scale plans of different neighborhoods to investigate their location, population, climate, economy, industry, history, and natural vegetation; the environmental problems that their residents encounter; and their roads, buildings, and other areas, and possible actual dimensions of them; and
- Investigating different people’s involvement in designing a neighborhood.

By reference to information collected through their investigations and discussions throughout their outside classroom work, each group decided their groupmates’ professional roles and their group leader. Following this, each group started to construct their scale plan considering the requirements provided above. Throughout creating their scale plan, the classroom teacher interacted with the groups, answered the students’ questions, and prompted them to explain their choices and to consider different alternatives. Although the project was set up as a contest between the groups, they were introduced that every project can win the contest as long as it fulfills all requirements.

Data collection and analysis

Classroom observations (abbreviated as O) and interviews (abbreviated as I) with the students depending on their available time during the treatment let us document students’ engagement with EDPs. Classroom observations and semi-structured interviews were conducted during and after the treatment. Each class was audio-recorded. Each interview conducted individually was also audio-recorded. There was no time limitation for the interviews. Interview questions are as

follows: “What resources did you use while making the outside-classroom search? What information did you find?”, “Did you encounter any difficulties while creating your scale plan? If any, what kind of difficulties did you encounter? What did you do to overcome them?”, “How did you decide the types of polygons for ground areas covered by buildings and other areas of your scale plan?”, “Did you like/dislike creating your scale plan?”, and “What did you learn from creating your scale plan?” Please refer to the paper on the PBL environment (see Ubuz & Aydinyer, 2019) for the other details about interviews.

The tapes from the classroom observations and interviews were then transcribed. The transcripts were then segmented into units of text in preparation for coding. Each segment represents one idea. Segmenting was done independently by the two researchers, checked for reliability, and any inconsistencies were resolved. The average reliability for segmenting was 94%. Once the segmenting was completed, data analysis was conducted. Each segment was coded with respect to EDP characteristics and their key aspects in the coding scheme (Berland et al., 2014). This process was fluid—a single utterance could speak to multiple EDP characteristics, and each characteristic could be addressed multiple times throughout the observation and interview.

Findings

The findings are provided around the aforementioned four characteristics of the EDP.

Defining the problem

Right after the teacher introduced the driving question and announced the project groups, some of the students were worried about the difficulty of the project because they told that they have not created such a multidimensional project in mathematics lessons before. The project, however, attracted most of the students’ attention. At break after the lesson in which the question was introduced, FM16 and FI20 tried to make a rough sketch and some groups that came together with their groupmates (a) talked about the relation between the project and their future career plans and (b) decided their group leader. At first, a few FIs (e.g., O-FI6), however, were unhappy with their groupmates. They preferred to choose their groupmates themselves as groupmates need to have more responsibility to create the project. However, after completing their project with previously announced groupmates, their entertainment and engagement with the project helped them compensate such prior negative feelings.

I-FD18: Even though we had disagreements with each other at first, everything was resolved with the help of my groupmates in the project.

O-FM11: I already want to be an architect, so this project is going to be helpful for me.

I-FI6: At first, I did not like it because we preferred to choose our groupmate. But then, I liked it. I liked your teaching style. You gave us to create somethings and ...

As a result of communicating with different people (e.g., their parents, relatives, social studies teacher, headman) and conducting research from various sources (e.g., the Internet, books, a map, other sources), so much information were found about the following issues related to designing a neighborhood: (a) the geographical position, population, climate, economy, industry, history, and

natural vegetation of some places; (b) the environmental problems (e.g., air pollution, noise pollution, lack of green areas, traffic congestion, global warming, unplanned urbanization) that their residents encounter; (c) their roads, buildings, and other areas, and possible actual dimensions of them; and (d) different people's involvement in designing a neighborhood). Subsequently, the information to be used was determined and summarized. In the stage of deciding on the profession of each group member, they mostly chose to be an engineer, an architect, and a city planner regardless of their cognitive style. There was definitely at least one student from each of these three professions in each group. In those with four members in the group, the fourth member decided to be either a minister (one FD, one FM and two FIs), a chief physician (one FI), a lawyer (one FM), a sociologist (one FD), and assistant of an engineer (one FD). Distribution of group leaders according to their cognitive styles were: FMs (58%), FIs (29%) or FDs (13%). Mostly FMs were chosen as a group leader.

Generating and selecting between multiple possible solutions

All students were active throughout determining the elements of the neighborhood. Besides FMs and FIs, it was interesting to see that some FDs (e.g., I-FD17, I-FD20) also focused on the details regarding to real life issues (e.g., an interesting property of a certain plant, what difficulties architects encounter while doing their job). All these details allowed them to understand the world around them. They became aware of various things about their own neighborhood and the population of a neighborhood.

O-FD4: I did not know that we (my family) live in a neighborhood.

I-FD17: I easily found information from the Internet by selecting appropriate keywords... We are going to choose black pine for green areas [for our scale plan] because we learned that it produces more oxygen compared to other types of trees.

I-FD20: I realized that drawing is not an easy work and a mistake can destroy everything if architects are not careful when designing [a place].

O-FM23, O-FM35 and O-FI1 from different groups: We have learned what the population of a neighborhood can be.

Some groups had disagreements in determining the placement of the buildings and other areas in the scale plan. For example, to decide the place of a police office in the neighborhood, after O-FM3 said, "the police office should not be at the center", her groupmate O-FI6 said, "No, it should be in the center to catch up with thieves easily (in case of theft)." To decide the place of a playground, O-FD5 from the same group said, "FI6 wants to make a playground for children close to the road; it should not be like that". They solved such disagreements by considering the comfort and safety of the residents and attractive appearance of the neighborhood. They decided to locate some commonly used buildings (e.g., those for shopping, education and administration) in the center of the neighborhood and close to each other. They also decided to locate some buildings and areas whose purposes were interrelated, in close locations to each other. Placing a fire department, a water tank and a forest close to each other to make it easy to put out the possible fire can be one example for that. Whenever they could not be able to choose one of the different ideas

in determining the placement of the buildings and other areas in the scale plan, they used different other strategies such as voting what idea to use, and using the suggestions of either the majority or the group leader. At first, some FIs (e.g., I-FI22) resisted having their groupmates accept their ideas and did not try to compromise among different ideas in the groups. Then, however, so as not to waste time to complete the scale plan, these FIs stated that they did not insist on using only their own ideas and agreed on the idea of the majority.

Modeling and analysis

Regarding to deciding the polygonal shapes representing ground areas of each building and other areas, all students chose certain types of polygons considering the buildings' ground areas in reality such as using squares for houses, rectangles for an administration building, and a trapezoid for a taxi rank having slanted parking lots. They also included regular polygons to have a pleasing and attractively appearing and architecturally good-style neighborhood. They used nested or side by side polygons for relevant buildings such as for different schools as well. Regarding the side lengths and angle measures of polygonal shapes and the width and length of the roads on the plan, they had difficulties with considering these measurements in reality and adapting them on the scale plan, and realizing that polygons representing ground areas in reality and on the scale plan are similar and they have congruent angles. For example, O-FD29 said, "We must multiply every (angle) measure (of an isosceles triangle) on the plan by 250 (the scale of the plan) in order to find (angle) measurement of it in reality." Later, she remembered that the sum of interior angles of a triangle is always 180 degrees, and then said, "Yes... They (angle measurements of polygons) must be the same (both in the plan and in real life)". Actually, the FDs, FMs and FIs behaved differently for some groups throughout deciding measurements. For example, to decide the lengths of the roads on the scale plan, they, especially FMs and FIs, developed their own strategies. To give examples to these strategies, using a 30-cm ruler, O-FM21 and O-FI15 from different groups measured one side length of the A4 paper's used for their rough sketch, and its corresponding side length of the cardboard's used for their scale plan. Then, they, respectively, utilized their existing mathematical knowledge (e.g., constructing a proportion using these measures) and found the length of the road on the scale plan by solving this proportion. These FMs and FIs explained these strategies to their groupmates as well and directed them to use these strategies to find other road lengths on the plan as follows:

O-FI15: I found something (*He told his groupmates to measure particular lengths and they measured them using a ruler. Then, he said and asked that*) the length of A4 paper is 28 cm and that of the road on it is 7.5 cm. Then, what would be the length of the road on the plan if that of the cardboard is 68 cm?

O-FM20: (*He called the teacher and asked*) can we take a calculator?

The groupmates: (*They found the length of the road on the scale plan by solving the proportion $\frac{28}{7.5} = \frac{68}{x}$ constructed by O-FI15 and by using a calculator.*)

The difficulties experienced while drawing the scale plan using a protractor and a ruler were solved by trying again and again, and with the help of their groupmates and the teacher.

I-FM1: We had the difficulty with drawing these shapes. A volunteer came out and drew these shapes. This is how it was solved. Or, our groupmates FI1 and FI2 wanted to draw the same shapes and they solved it by drawing them in order.

O-FM28: *(He warned his groupmate O-FI26 on her drawing and said)* Be careful, the angle you constructed is 35 degrees instead of 45 degrees.

I-FI25: We corrected our mistakes (regarding to drawing) by helping each other.

The students stated that they liked different parts of creating their scale plan. They, however, mostly stated their enthusiasm with drawing the scale plan using a protractor and a ruler. This is because they felt a sense of ownership of their scale plan by acting as architects and constructing a tangible outcome.

I-FD27: I am interested in designing and creating places. I was interested in thinking of myself as an architect. I like drawing. While preparing this project, I realized that drawing is not easy, but it is very enjoyable.

I-FM26: This project was different from the other projects we did before. It made us think, imagine, and use our hand skills. It was difficult but I think we accomplished. It was exciting to put myself into an architect's position for a while. I want to be an architect in the future because I liked drawings.

I-FI29: I hadn't decided about my future career plans. However, I experienced what an architect do with this project. How they measure, how they draw, how they use the scale? Architecture began to dominate. I learned what difficulties architect face with projects.

Iteration

When needed, all students reconsidered previously made decisions and made some adjustments to improve their scale plan. But, especially FMs and FIs emphasized how they dealt with unexpected situations (e.g., having some polygons not fitting into the cartoon, having more empty space in the plan). In situations requiring various adjustments, all students made an effort to do what was necessary such as changing some polygonal shapes, angle and side measurements or the placements of the elements in the plan to fit them into the cardboard, or adding some extra polygons to fill in the blanks in the plan.

I-FM14: Something we planned in the rough sketch did not fit into the plan since there was not enough space. So, we changed the placement of the buildings (in the neighborhood).

O-FM20: We thought (the shape of ground area of) this building as a parallelogram but it did not fit into the plan. We changed this parallelogram into a trapezoid.

I-FI14: We had difficulty with measurements and drawing some shapes, but we changed some measurements later.

Conclusion

This study has indicated that all students were active throughout four phases of EDP. The structured PBL environment seemed to accommodate the needs of students with different cognitive styles because of contextualizing, visualizing, and collaborating opportunities in this

environment. FMs and FIs were better than FDs in developing different strategies to help them continue the project and in reconsidering previously made decisions, if needed. This reveals that FI/FMs were more able to aware of and dealt with problems and challenges. In addition, FIs' awareness of difficulty in developing such a multidimensional scale plan helped them realize that they needed their groupmates' contribution and learned not to resist on their ideas.

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