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Abstract: In this paper we explore 7^th grade 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 together with opportunities to learn and apply mathematics. The results show that project-based learning engages students in engineering design processes while designing a two-dimensional scale plan of a neighborhood as a project.

Keywords: 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). While engaged in a project, following an engineering design process (EDP) allows systematic learning, simultaneously exposing students to experience the cognitive processes of an engineer (Tate, Chandler, Fontenot, & Talkmitt, 2010).

The key features of PBL (e.g., Markham, Larmer, & Ravitz, 2003) are to encourage students' learning and develop the essential knowledge and skills to engineer a personalized solution to the design problem (Chua, Yang, & Leo, 2014). Even though many works have been conducted on PBL, none has specifically tailored to document students' engagement with EDP. To do this, this paper focuses on documenting students' engagement with EDPs while designing a two-dimensional scale plan of a neighborhood in a 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). Specifically, this paper is guided by the following research question: How do students engage with the EDP in the PBL environment?

Methodology

Participants

The participants in the present study included those students for whom Project Based Geometry Learning (see Ubuz & Aydınyer, 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, consisting of 57 females and 40 males, in three intact classes from a private school in Ankara, Turkey were the participants.

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 Group Embedded Figures Test. Each group included at least one student from each cognitive style (field dependent, field mixed, and field independent) 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 were shown by projecting them on a large screen to discuss 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 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 & Aydınyer, 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

After the teacher provided the driving question, each student simultaneously communicated with their parents, relatives, social studies teacher, and headman, and conducted research from various sources (e.g., the Internet, books, or other sources). From their parents and relatives, he/she received information regarding their profession (e.g., engineering, architecing, landscape architeching, city planning). From their social studies teacher, he/she got information about the geographical position, population, climate, economy, industry, history, and natural vegetation of some places. From the headman of their neighborhood, he/she got a sample plan of their neighborhood and information about the requests and complaints of the residents. Through searching the Internet, books, or other sources (e.g., atlas, maps, encyclopedias), he/she found (1) some sample scale plans of different neighborhoods, (2) articles on designing a place, (3) the standards of designing a neighborhood (e.g., the number of floors of buildings should be adjusted according to the population of a neighborhood, wider streets are needed to be established if the neighborhood is close to the city center to be reached quickly and easily), (4) the elements of a neighborhod (e.g., roads, buildings and other areas), and (5) actual side lengths of the ground areas of the buildings and other areas as well the width of the roads. Regarding to a particular neighborhood, he/she found its (1) geographical position (e.g., latitude and longitude, neighboring places, whether it is mountanious or by the sea, a town belongs to which city), (2) population, (3) climate (e.g., average highest and lowest temperature each month, continental or Mediterranean climate), natural vegetation (e.g., woodland bush), (4) growing products (e.g., fruit trees, vegetables), economy and main sources of income (e.g., agriculture, tourism, industry), (5) history (e.g., historical and cultural buildings and other areas in it), and (6) environmental problems that the residents encounter.

> I-S17: I have learned what professional owners of city planners, architects, engineers, and landscape architects do. 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.

Upon their investigations, they realized that the main environmental problems were air pollution, noise pollution, lack of green areas, traffic congestion, global warming, and unplanned urbanization; and different elements (e.g., roads, buildings, other areas) needed for the residents of a neighborhood regarding residence, health, education, administration, shopping, transportation, entertainment, doing sports, recreation, eating-out, and religion. Additionally, they realized what professions should be included in a common project to design a place, what they do, and their training process at a university. Upon this, each groupmate decided his/her profession. They mostly chose to be an engineer, an architect, and a city planner. Then, the groups decided where to design a neighborhood. Most of them decided to design it in different places (e.g., big cities, small towns, seaside, island, etc) in Turkey and a few in abroad.

To accommodate a neighborhood they wanted to design that is sustainable, walkable, vibrant, social, and livable, the groups started to make decisions to solve the issues the residents of the neighborhood encounter regarding the location, population, climate, economy, industry, history, natural vegetation, environmental problems, roads, buildings, and other areas.

As emphasized above, the main goal was to improve existing residential communities. The problems raised in the context of this main goal can be listed as follows:

1. What could be the elements of the neighborhood and the places of them?
2. What could be the polygonal shapes of each building and other areas?
3. What could be the side lengths and angle measures of polygonal shapes representing ground areas of the buildings and other areas in real life and on the plan considering the scale together?

4. What could be the positions of roads with respect to each other using positions of three lines in a plane?
5. What could be the width and length of the roads on the plan?
6. How can we draw and place polygons and roads agreed upon on the scale plan using a protractor and a ruler?

The first problem is about deciding the issues related to the scale plan and the following four problems are about deciding geometric representation of the physical environment in the neighborhood, while the last is about drawing the scale plan.

Generating and selecting between multiple possible solutions

Regarding the first problem, the students decided the elements of a neighborhood and the placement of them in it based on their communication, search and investigation emphasized in the previous part. Regarding the elements of a neighborhood, they mostly decided to include houses for residence; buildings of health clinic and pharmacy for health; schools for education; bank, headman's office, fire department, police office and post office for administration; market place and shopping center for shopping; bicycle routes, bus station, parking lot, petrol station, roads and taxi rank for transportation; theatre and cinema for entertainment; areas to do different kinds of sports; green areas and playgrounds for kids for recreation; and restaurant for eating-out. They also included different cultural and religious areas in their plan to be respectful to people from different cultures. They planned to protect existing historic and cultural places as well as natural beauties. Furthermore, depending on the place of the neighborhood, they included other areas such as a harbor if it is by the seaside. It was interesting to observe that some groups decided on cultivating particular fruit trees and vegetables according to the climate of the neighborhood so that the residents can do their own organic farming. They also decided to have buildings that are not too high to solve unplanned urbanization.

In determining the placement of the buildings and other areas in the scale plan, students usually made suggestions within their professional roles. The suggestions of the students in different roles were discussed within the groups and then a common decision was reached. Throughout the presentations of their project to the class, for example, they said the following as a group:

> As a landscape architect and the group leader, I (O-S12) advised to design green areas as large as possible…The reason that we chose this neighborhood was its unplanned urbanization. We tried to give importance to the aesthetic [appearance of it]... As a city planner, I (O-S13) advised to place buildings such as a pharmacy, a fire department, a police office, and schools in the center of the neighborhood so that the residents could be able to reach them easily… As an architect, I (O-S16) advised not to include the two houses very next to each other… We have learned how to design a place while developing this project… As an engineer, I (O-S21) decided the measurements of buildings and roads in real life and on the plan…

Regarding the second problem, they determined polygonal shapes of the buildings and other areas to be placed in the plan by considering the ground areas of the buildings and other areas in reality (e.g., squares and rectangles for football field, houses, and administration buildings). Furthermore, to fit the polygons into the plan and to fill the blanks on it, they considered the polygons' number of sides, angle measures, and positions with respect to each other and with respect to the positions of the roads. They also included regular polygons (e.g., squares for houses which are symmetrical to each other and a regular hexagon for a theatre) to have a pleasing and attractively appearing and architecturally good-style neighborhood. They chose a triangle for having small areas such as a museum and a bus station, and some polygons having more than three sides to have larger areas (e.g., for green areas). They also used nested polygons for buildings used for similar purposes (e.g., for education). They chose trapezoids, parallelograms, and rhombi for buildings which had narrower and wider parts (e.g., for taxi ranks).

Regarding the third problem, they considered the interior and exterior angle measures and the side lengths of polygons representing the ground areas of the buildings and other in real life. They had difficulty with estimating the lengths of the ground areas of the buildings in real life. For example, O-S23 asked, "Is the width of this class 25 meter-long? I want to visualize how long 25 m is." The teacher let her and her groupmate O-S25 measure the length of the classroom using a 1-m ruler and they found it to be approximately 8 meters. Regarding the fourth problem, they decided to include parallel and crossing roads to solve traffic congestion and unplanned urbanization.

Modeling and analysis

Regarding the third problem, they needed to realize that a polygon to be placed on the plan and its shape in real life are similar. Then, first, considering that all corresponding angles of two similar polygons are congruent, they decided to have equal corresponding angle measures of a polygon to be placed on the plan and its shape in real life. Second, considering that all lengths of corresponding sides of two similar polygons are proportional, they decided the scale of the plan (i.e., 1:250) by thinking about the side lengths of the rectangular white cardboard to be used to draw their plan (48 cm by 68 cm), and the side lengths (120 m by 170 m) of the rectangular smooth surface they want to make a neighborhood. To do that, they converted the side lengths of the rectangular smooth surface from meter to centimeter to make the units the same and calculated the ratio of the length of the rectangular white cardboard to its corresponding actual side lengths in the rectangular smooth surface. Third, considering their decisions regarding to the actual side lengths of the polygons representing the ground areas of the buildings and other areas, they calculated the side lengths of the polygons to be placed on the plan using the scale of the plan (1:250) by first converting the actual side lengths of the polygons in real life from meter to centimeter. Regarding the fifth problem, considering their decisions regarding to the actual width of a road (e.g., 10 m), they calculated the width of a road (e.g., 4 cm) to be placed on the plan using the scale of the plan (1:250) by first converting the actual width of the road from meter to centimeter.

Regarding the last problem, to draw their scale plan using a protractor they did not know how to use it to measure a particular angle and/or how to draw an angle having a particular measure. The teacher or groupmates helped the students who did not know how to use it. Besides that, minor mistakes in their drawings regarding to the angle measures or side lengths of polygons made them unable to draw the shapes they wanted to make.

O-S4: We could not draw a parallelogram with 100 and 80 degrees of angles, could you show us?

O-S4: We tried to draw a regular hexagon whose side [lengths] are 2.5 cm. We were careful with [drawing] its angle measures but the sixth [side] length became 3 cm instead of 2.5 cm.

Iteration

Although the students mostly worked in a definite order to create their scale plan (i.e., deciding the issues related to the scale plan, constructing two-dimensional geometric representation of the physical environment, making a rough sketch of the plan, and drawing the scale plan, respectively), they sometimes needed to reconsider previously made decisions and make some adjustments to improve their scale plan. The first remarkable iteration needed when the teacher noticed the errors in students' decisions regarding to the angle measures and side lengths of the polygons representing the ground areas of the buildings and other areas. Based on the teacher warning (e.g., "Be careful about the …"), they needed to reconsider their incorrect decisions regarding to the angle measures and/or side lengths of polygons. This incorrect decision is due to three reasons. The first is the confusion of the exterior and interior angle measures of a polygon (e.g., deciding 60 degrees rather than 120 degrees for each interior angle measure of a regular hexagon). The second is not realizing that the polygons that represent ground areas of the buildings in real life and their corresponding polygons on the plan are similar. For this reason, they calculated the side lengths as well as the angle measures of the polygons on the plan on the basis of the scale. They then noticed that the polygons representing ground areas of the buildings in real life and their corresponding polygons on the plan are similar. That is, the angle measures of polygons representing ground areas of the buildings in real life and their corresponding polygons on the plan are the same. The last is a mistake on converting a unit to another unit (e.g., converting a side length from meter to centimeter by dividing rather than multiplying by 100). The second remarkable iteration occurred when they encountered difficulties while drawing the scale plan (e.g.., not being able to draw the polygon they want to construct, having some polygons not fitting into the plan, having more empty space in the plan). Not being able to draw the polygon they want to construct made the students realize the importance of accuracy and precision in measurements, as mentioned in the previous part. Not fitting into the plan or having more empty space in the plan made them revise their rough sketch and prior decisions regarding the polygonal shapes and their angle measures and side lengths.

I-S20: I realized that drawing is not an easy work, and even a small error can destroy everything if architects do not pay attention to their drawing.

O-S20: We thought this building of the neighborhood as a parallelogram, but it did not fit into the plan. We changed this parallelogram into a trapezoid.

Conclusion

This study has proven that designing a two-dimensional scale plan of a neighborhood in the PBL environment engages students in EDPs 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. To achieve the goal of graduating students who are competent in EDPs, we need to continue to use PBL in schools. In sum, PBL environment builds on EDP as the cornerstone and as the foundation on which students bring their compartmentalized knowledge of science (e.g., types of trees that produce more oxygen compared to other ones), technology (computer, ruler, protractor), mathematics (angle and side properties of polygons, inclusion relationship between the polygons , e.g., "Is square a rhombus?", similarity and concurrence of polygons, angle and side properties of regular and irregular polygons) to bear on solving real-world problem. Furthermore, throughout designing a neighborhood plan, they learned how to design a place, the different types of professions and their duties, how to use a protractor to draw geometrical shapes, how to solve the challenges and difficulties as a group, the importance and value of geometry in real life, how the elements of a neighborhood are placed in it, and the importance of every detail such as accuracy and precision in drawings.

References

Berland, L., Steingut, R., & Ko, P. (2014). High school student perceptions of the utility of the engineering design process: Creating opportunities to engage in engineering practices and apply math and science. *Journal of Science Education and Technology, 23*(6), 705–720. doi: 10.1007/s10956-014-9498-4.

Capraro, R. M., & Slough, S.W. (2013). Why PBL? Why STEM? Why now? An introduction to STEM Project-Based Learning: An integrated Science, Technology, Engineering, and Mathematics (STEM) approach. In R. M. Capraro, M.M. Capraro, & J. Morgan (Eds.). STEM-*Project-based learning: An integrated Science, Technology, Engineers and Mathematics (STEM) approach* (p.1–5). Sense Publisher.

Chua, K. J., Yang, W. M., & Leo, H. L. (2014). Enhanced and conventional project-based learning in an engineering design module. *International Journal of Technology and Design Education, 24*(4), 437–458. doi:10.1007/s10798-013-9255-7.

Markham, T., Larmer, J., & Ravitz, J. (2003). *Project-based learning handbook: A guide to standards-focused project-based learning for middle and high school teachers* (2nd ed.). Novato, CA: Buck Institute for Education.

Tate, D., Chandler, J., & Fontenot, A. D, & Talkmitt, S. (2010). Matching pedagogical intent with engineering design process models for precollege education. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing, 24*(3), 379–395. doi: 10.1017/S0890060410000260.

Ubuz, B., & Aydınyer, Y. (2019). Project-based geometry learning: Knowledge and attitude of field-dependent/independent cognitive style students. *The Journal of Educational Research, 112*(3), 285–300. doi: 10.1080/00220671.2018.1502138.

Ubuz, B., & Erdogan, B. (2019). Effects of physical manipulative instructions with or without explicit metacognitive questions on geometrical knowledge acquisition. *International Journal of Science and Mathematics Education, 17*(1), 129–151. doi:10.1007/s10763-017-9852-0.