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Theme-based Project Learning: Design and Application of Convergent Science Experiments

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Abstract This case study aims to verify the benefits of theme-based project learning for convergent science experiments. The study explores the possibilities of enhancing creative, integrated and collaborative teaching and learning abilities in science-gifted education. A convergent project-based science experiment program of physics, chemistry and biology with the theme of environment such as seawater and wetland was designed and applied to science-gifted secondary school students in an international science contest. The program was initiated with integration of physics, chemistry and biology, interrelating both field work and laboratory work. Besides, logical discussion and humanistic writing activities with environmental issues were followed. The participants were tasked to conduct hands-on multi-disciplinary projects for both in the fields and laboratories. The projects involve raising creative and critical thinking through interpreting collected data, predicting outcomes, drawing conclusions, and presenting results. The study shows a model of project-based convergent programs for integrated experimental composition to facilitate collaborative and creative learning as well as to improve students interests in related subjects. The study discusses ways to raise awareness of benefits from multi-disciplinary approaches through theme-based project learning in science-gifted education.

Keywords Theme-based Learning, Project Learning, Integrated Education, Convergent Experiment Program, Multi-disciplinary Course Design, Science Gifted Education, Sea Water, Wetland

1 Introduction

Project-based learning is grounded in constructive approaches for it is designed to motivate students to be more actively involved in activities [1]. Crook featured a collaborative learning environment in project-based learning and teaching. Collaborative learning through projects helps to promote learner autonomy and lower affective filters[2]. The benefits of theme-based project learning have been researched in various academic fields for educational subjects. Project-based teaching and learning is popularly implemented to provide opportunities for students to engage with academic subjects authentically [3, 4]. It supports the idea that hands-on projects help develop integrated learning and activate knowledge into practical applications. In addition, the advantages of convergent science experiments provide the possibilities of enhancing creative, integrated and collaborative teaching and learning abilities.

2 Overview

A convergent project-based science experiment program of physics, chemistry and biology with the theme of environment such as seawater and wetland was designed and applied to science-gifted secondary school students in an international science contest. The participants were tasked to conduct hands-on multi-disciplinary projects for both in the fields and laboratories as shown in Table 1 and 2. The projects for humanity work like creative writing with related topics and formal presentations for participants research results help finalize the whole thematic process. The experiment programs of the project were purposely designed to utilize online resources for the benefits of accesibility and readiness.

Figure 1 shows the framework of the convergent science experiment model and Figure 2 outlines the timeline of each activity for the whole program.

3 Procedure/Content

Participants were tasked to conduct field research to collect the samples of various types of plankton to study the interaction with diversities and the nitrogen cycle in seashore and wetland ecosystem for the section of biology [6, 7]. Other components of the program require

Table 1. Field Work Experiments

FIELD WORK EXPERIMENTS I		
Biology A	Title	Nitrogen Cycle [6]
	Purpose	To measure the concentration of nitrogen
	Process	1. Find 3 suitable areas.
		2. Collect water samples from 3 different locations.
		3. Measure Nitrate of the water sample with a given test kit.
		4. Solve problems about nitrogen cycle.
Biology B	Title	Collecting Plankton
	Purpose	To collect and fix plankton from water samples
	Process	1. Filter the sampled water with a plankton net.
		2. Transfer the filtered water and fix the plankton.
		3. Mark the plankton and submit it to the staff.
Chemistry	Title	Identifying Ionic Compounds
	Purpose	To determine the ionic compounds of 8 numbered bottles
	Process	1. Place a base plate horizontally using a level gauge.
		2. Observe precipitation, color changes, and complex formation.
		3. Infer the components of ionic compounds by using the results of responses.
FIELD WORK EXPERIMENT II		
Physics	Title	Principles of Sundial[8]
	Purpose	To make your own sun-dial using a base plate, level gauge, graphic paper and a rod.
	Process	1. Record the path of shadow.
		2. Determine the trajectory of the sun.
		3. Predict the time and location of sunset.
Chemistry A	Title	Alginate Reaction
	Purpose	To make a mold for sea side environment
	Process	1. Practice and set up the reaction condition.
		2. Select places and lay an outline.
		3. Mix alginate powder and water with a spoon.
		4. Pour the paste and wait for the reaction.
		5. Write your team name on the back side of cast.
		6. Write a report to explain the cast and location.
Chemistry B	Title	Ionic Chemical Reaction [9, 10]
	Purpose	To determine major components of sea water
	Process	1. Mix sea water and the liquid of each bottle.
		2. Observe and report the reaction of precipitation or color change.
		3. Infer the components of sea water by using the observation data.

measuring the salinity level of student-collected seawater samples with self-made salimeters for, and identifying the major components in seawater from the reactions of ionic compounds along with making sundials to predict the time path of the sun and creating alginate molds for surrounding seashore environments in the sections for physics and chemistry.

The program was initiated with integration of physics, chemistry and biology, interrelating both field work and laboratory work. Besides, logical discussion and humanistic writing activities with environmental issues were followed.

The internationally organized groups of contestants gather the experiment results of both field and laboratory work and utilize them to report, which gives them opportunities to raise the importance of integrative and logical approaches. Throughout the process creative humanistic writing is able to be combined to diffuse creative thinking.

Each team finalizes the participation by performing public presentation at the final conference which decides the winners of the contest. The final project provides the contestants with occasions to appreciate collaboration and integration.

4 Results and Discussion

4.1 Subject Analysis

Questionnaires were conducted after the science camp and the satisfaction and effectiveness of the science programs were analyzed from the perspectives of science education for gifted students. The analyzed questionnaire results were arranged by each subject and categories of consideration. Forty participants to the science camp responded the questionnaire. For the question of overall satisfaction, one participant did not mark and six participants checked only the overall question and did not answer sub-categorized questions. The choices of answers were ranked in numbers with the ranges from 1, *strongly agree* to 5, *strongly disagree*. Therefore, if the statistical number is lower, it means the participants agree with the question more. The mode of each question was number one, '*strongly agree.*'

Table 3 shows the easiness, necessary prior-knowledge, degrees of new learning and enjoyability of physics projects differentiated in field and laboratory work. The analysis reveals that although physics field work is more difficult and needs more prior knowledge than laboratory work, the participants find it more rewarding and enjoyable.

Table 2. Laboratory Experiments

LABORATORY EXPERIMENTS		
Biology	Title	Identification of Plankton [7]
	Purpose	To Identify Plankton of UPO Wetland [5]
	Process	1. Observe the fixed plankton from the field work with a microscope.
		2. Select the most common plankton from your sample.
		3. Record the features of the plankton.
		4. Include a detailed drawing of the specimen.
		5. Identify at least 5 of your specimen.
Physics	Title	Salimeter Design[11]
	Purpose	To design Your Own Salimeter
	Process	1. Draw a schematic diagram and design concept.
		2. Fabricate your salimeter.
		3. Make reference salinity solution using salt and water.
		4. Calibrate your salimeter with prepared solution.
Chemistry A	Title	Mohr method for chloride [12, 13]
	Purpose	To determine chlorides by titration with silver nitrate
	Process	1. Pipet aliquot of chloride solution into 250 mL Erlenmeyer flask
		2. Add 1 mL of 5% potassium chromate solution (as indicator)
		3. Titrate with silver nitrate solution till the first color change (from yellow to red)
		* Consider the blank titration
Chemistry B	Title	Salinity
	Purpose	To measure salt content of seawater with Mohr method
	Process	1. Weigh the empty 250 mL dried Erlenmeyer flask
		2. Put the around 2.500g 3.200 g of seawater to Erlenmeyer flask and measure the exact weight
		3. Add 100 mL D.I water to seawater
		4. Add 1 mL of 5% potassium chromate solution (as indicator)
		5. Titrate with silver nitrate solution till the first color change (from yellow to red)
		6. Repeat 1 6 procedure for 5 times
		7. Compare the data from salinity electrode
		* Consider blank titration
		* Calculate the average and standard deviation

Table 4 shows the easiness, necessary prior-knowledge, degrees of new learning and enjoyability of biology projects for field and laboratory work. The analysis reveals that biology laboratory work is easier and more enjoyable and needs less prior-knowledge. The participants learned more from field work than laboratory work.

Table 5 shows the easiness, necessary prior-knowledge, degrees of new learning and enjoyability of chemistry projects for each field and laboratory work. The analysis reveals that although chemistry field work is more difficult than laboratory work, field work is more enjoyable and the participants learned more new things from field work. As showed in the level of difficulties, field work needs more prior-knowledge than laboratory work.

4.2 Categorical Analysis

4.2.1 Level of Easiness

Analysis of level of easiness is summarized in Table 6. The analysis shows that the participants found biology work the easiest, followed by chemistry and physics the most difficult. Except physics, the difficulty of chemistry and biology work is easy or average. The interesting point is that for all three subjects, laboratory work is considered easier than field work. It can be inferred that on the basis of the multi-national camp participants, either biology is more familiar to various nations or the biology topic, plankton observation, is widely included in their science curricula. It is possible to infer, though it is not exactly clear, that their science education is generally conducted on laboratory work rather than field work.

4.2.2 Needs of Prior Knowledge

Analysis of needs of prior knowledge is summarized in Table 7. The participants responses show that chemistry field work with precipitation needs the most prior knowledge, followed by chemistry laboratory work. Physics field and laboratory work is marked the second and as it could be estimated from the question of difficulty level, biology work needs the least prior knowledge. In all three subjects field work needs more prior knowledge than laboratory work which is consistent with the find-

Table 3. Results of Physics.

Category	Easy	Prior -knowledge	New learning	Enjoyable
Field Work	3.29	2.18	1.59	2.12
Lab work	3.00	2.44	1.97	2.35

1. strongly agree 2. agree 3. neutral 4. disagree 5. strongly disagree

Table 4. Results of Biology.

Category	Easy	Prior -knowledge	New learning	Enjoyable
Field Work	2.38	2.59	1.62	1.68
Lab work	2.24	2.71	2.03	1.59

1. strongly agree 2. agree 3. neutral 4. disagree 5. strongly disagree

ings from the level of difficulty. It can be inferred that the need of prior knowledge tightly correlates with the difficulty level and the lack of prior knowledge could impede the process of the projects. Therefore, guided introduction to the materials and protocols needs to be specified prior to the conduct of the projects.

4.2.3 Learning New Things

Analysis of learning new things is summarized in Table 8. It is recognizable that whether the participants learned new things or not is unlikely to correlate with the difficulty level and need of prior knowledge. Although the difficulty level is highest in physics field work, sundial, the participants responded that they learned the most from that project. The biology field work, Nitrogen cycle and Diversity of Plankton, which is considered the easiest is ranked the last for learning new things. The participants learned new things more from field work in all three subjects, which can lead to the inference that projects with a high-level difficulty are more likely to provide chances to new things.

4.2.4 Enjoyablity

Analysis of enjoyablity is summarized in Table 9. The participants responses show that biology is the most enjoyable subject followed by chemistry and physics. In biology, laboratory work is more favored to field work. However, field work is more favored than laboratory work for both chemistry and physics. For the whole projects, over 40% of the participants responded they strongly agreed or agreed that the projects were enjoyable. It is thought-provoking that the degree of enjoyment complies with the level of difficulty.

4.3 Overall Discussion

Results of categorical analysis are summarized in Figure 3. The most significant finding is that all field work is more agreed than laboratory work on all categories. With field work viewed as more challenging and enjoyable, the participants learned new things more from field work than laboratory work. This indicates that as in the case of physics, it does not necessarily mean field work is easier but it provides participants with chances of motivation and interest. In terms of the subjects, biology laboratory projects offered an effective learning chance in an enjoyable environment with relatively easy tasks, although it demanded less prior knowledge. On the other hand participants responded that they needed more prior knowledge in chemistry but found it easier than physics in actual experiments. The fundamental difficulties in physics can be analogized out of these results. It is rather justifiable to comment that the high satisfactory level of biology projects is resulted from the familiar theme which is more suitable to draw various answers, not from the preference of its subject. In terms of each questionnaire category, learning new things is the most strongly agreed along with the strongly agreed difficulty level. Overall the participants evaluation for the camp is satisfactory with the range of 2.0±0.147 with standard deviation 0.918. These findings have implications that science projects under the given circumstances can be benefited more from less difficult topics creating more enjoyable and learnable experiences.

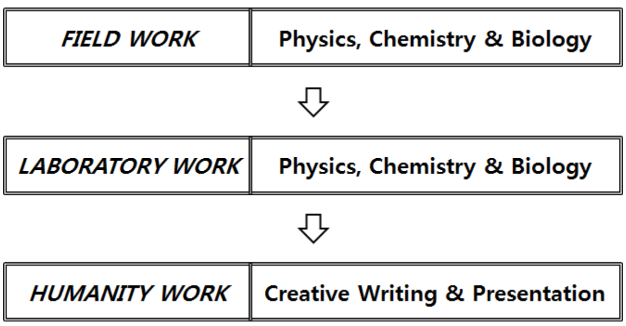

Figure 1. Convergent Science Experiment Model.

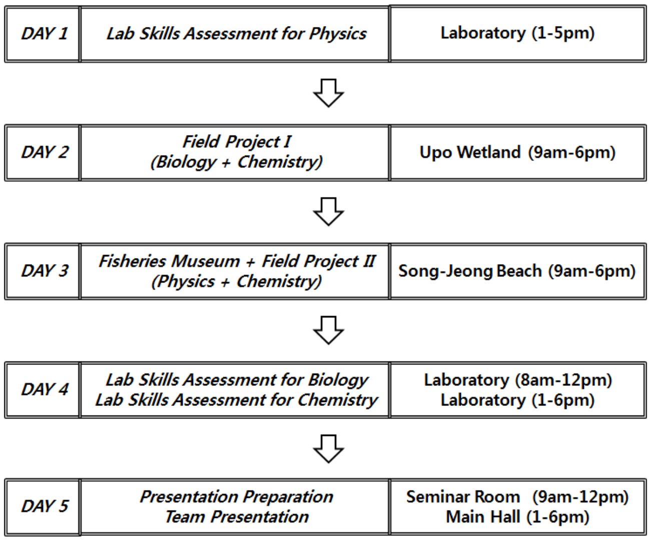

Figure 2. Timeline of Program.

5 Conclusions

The projects involve raising creative and critical thinking through interpreting collected data, predicting outcomes, drawing conclusions, and presenting results. The study shows a model of project-based convergent programs for integrated experimental composition to facilitate collaborative and creative learning as well as to improve students interests in related subjects. The model of convergent science experiment is able to raise awareness of benefits from multi-disciplinary approaches through theme-based project learning in science-gifted education.

Table 5. Results of Chemistry.

Category	Easy	Prior -knowledge	New learning	Enjoyable
Field Work	2.71	1.97	1.65	1.88
Lab work	2.65	2.00	1.85	2.09

1. strongly agree 2. agree 3. neutral 4. disagree 5. strongly disagree

Table 6. Level of Easiness.

It was easy	Freq of str agree	Freq of agree	Freq of neutral	Freq of disagree	Freq of str disagree	average	mode
Phys Field (Sundial)	1	7	11	11	4	3.29	3,4
Phys Lab (Salimeter)	4	5	13	11	1	3.00	3
Biol Field (Nitrogen cycle, Plankton)	8	10	13	1	2	2.38	3
Biol Lab (Plankton identification)	9	12	9	4	0	2.24	2
Chem Field (Precipitation)	6	6	15	6	1	2.71	3
Chem Lab (Argentometry of sea water)	5	7	18	3	1	2.65	3

Table 7. Needs of Prior Knowledge.

It needs prior knowledge	Freq of str agree	Freq of agree	Freq of neutral	Freq of disagree	Freq of str disagree	average	mode
Phys Field (Sundial)	11	11	7	5	0	2.18	1,2
Phys Lab (Salimeter)	10	10	5	7	2	2.44	1,2
Biol Field (Nitrogen cycle, Plankton)	7	8	11	8	0	2.59	3
Biol Lab (Plankton identification)	6	11	7	7	3	2.71	2
Chem Field (Precipitation)	11	15	7	0	1	1.97	2
Chem Lab (Argentometry of sea water)	13	11	9	2	0	2.00	1

Table 8. Learning New Things.

I learned new things	Freq of str agree	Freq of agree	Freq of neutral	Freq of disagree	Freq of str disagree	average	mode
Phys Field (Sundial)	21	9	2	1	1	1.59	1
Phys Lab (Salimeter)	18	4	8	3	1	1.97	1
Biol Field (Nitrogen cycle, Plankton)	20	9	3	2	0	1.62	1
Biol Lab (Plankton identification)	15	9	6	2	2	2.03	1
Chem Field (Precipitation)	19	10	4	0	1	1.65	1
Chem Lab (Argentometry of sea water)	17	8	7	1	1	1.85	1

Table 9. Enjoyablity.

It was enjoyable	Freq of str agree	Freq of agree	Freq of neutral	Freq of disagree	Freq of str disagree	average	mode
Phys Field (Sundial)	12	9	11	1	1	2.12	1
Phys Lab (Salimeter)	8	10	13	2	1	2.35	3
Biol Field (Nitrogen cycle, Plankton)	20	9	2	2	1	1.68	1
Biol Lab (Plankton identification)	21	8	4	0	1	1.59	1
Chem Field (Precipitation)	16	12	2	2	2	1.88	1
Chem Lab (Argentometry of sea water)	12	10	10	1	1	2.09	1

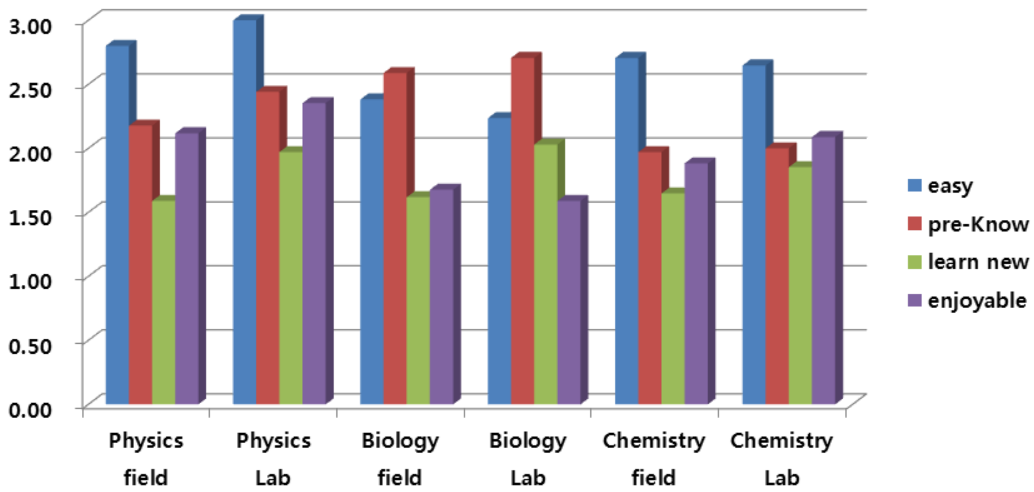

Figure 3. Averages of Categories.

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