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Effects of using invention learning approach on inventive abilities: A mixed method study

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This study aims to enhance inventive abilities for secondary students by using the Invention Learning Approach. Its activities focus on creating new inventions based on the students' interests by using constructional tools. The participants were twenty secondary students who took an elective science course that provided instructional units integrated with the Invention Learning Approach for 40 h, over a period of 20 weeks. A mixed-method approach was used to investigate and analyze the data. The results of this study indicated a significant increase in their inventive abilities. The qualitative data reported that students benefited from learning by this approach. Findings of this study can be used to determine how innovation and creativity can be fostered through the Invention Learning Approach teaching students how to be more innovative while solving real world problems.

Key words: Invention Learning Approach, inventive abilities, invention course, mixed methods.

INTRODUCTION

Competitiveness and productivity of an economy drive innovation, which continuously translates into patents for inventions. Developed nations have the largest number of invention patents. On the other hand, firms in developing nations request fewer patents. For example, more than 90% of patents applied for and granted by the Thai Patent Office are to foreign residents. Only a small number of patents are granted to local residents (STI Policy Office. 2011). Therefore, developing innovation abilities will allow developing nations to be more competitive in the global market (The Lemelson-MIT Program, 2003).

Thus, from clear needs and apparent trends, we have to prepare our people, especially the younger generation, to develop personal competitiveness and productivity in innovation, which will strengthen our societal ability to invent. Until now, regular schools have neglected to encourage students who have innate creativity to be innovative and produce new inventions. Rule et al. (2009) state that published research on efforts to improve children's inventive skills, especially at the secondary level, is almost nonexistent. Students must not be overlooked, but their latent ability to invent something new should be developed and supported at the national level. In order to do so, first, there should be research conducted in the development of an invention learning approach for children (The Lemelson-MIT Program, 2003).

Despite the fact that people everywhere have an innate ability to invent creatively, educators have largely ignored

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teaching invention, in spite of its role in transforming our world (Wiener, 1993). People think there is great mystery in inventing something (Gorman et al., 1995). However, Shlesinger (1980) stated, “If people-including children could be taught, for example, how to play a musical instrument, why couldn’t they be taught to invent? We can teach children to use their imagination to build a better world, to notice a problem, and fix it, to dream up a way life easier, and make it.” On the other hand, understanding how to teach students to become inventors is perplexing.

Currently, inventions are being used more to teach many disciplines. Several studies suggest that educational invention helps students gain content knowledge in subject areas (Westberg, 1996; Plucker and Gorman, 1999; Rule et al., 2009). In addition, Plucker and Gorman (1999) have suggested that teaching to invent plays a positive role in both learning and motivation. According to Rule et al. (2009), teaching students how to invent can increase students’ interests in engineering and science. Invention is multidisciplinary and covers many technical areas like science, math, engineering, design, and technology. Teaching students how to create inventions also provides them with an opportunity to identify how all the parts of a complex system interact and depend upon each other (Matinez and Stager, 2013). Many invention contests and programs have emerged over the two past decades. For instance, many schools supported “Invention Conventions”, the United States Patent and Trademark Office (USPTO) created the “Inventive Thinking Curriculum Project” (United States Department of Commerce (DOC), 1997), the National Science Teachers’ Association (NSTA) supported the “Young Inventors Awards” (Frankovitset al., 2002), and “Camp Invention” a hands-on creative science invention camp experimented with hundreds of partner schools (Saxon et al., 2003). In Thailand, the Ministry of Education has sponsored the “Young Scientific Invention Competition” yearly since 1991. Therefore, many Thai schools have tried to teach their students to create inventions for the competition. However, based on our interview of 40students and their teachers from the Young Scientific Invention Competition in 2012, we found that the students were not taught in their classrooms to create their own inventions. The supervisors guided all of the students in the creating of their inventions. Additionally, most of the ideas for the inventions came from the supervisors (Wongkraso et al., 2013).

Many previous studies have researched the effectiveness of the ways for teaching to invent including studying lives of inventors in order to teach students (McCormick, 1984), building Rube Goldberg-type inventions (Kuehn, 1985; Kuehn and Krockover, 1986), using step-by-step inventor approach programs (Shlesinger, 1982, 1987b), and scientific process skill programs or thinking skills (Kuehn and Krockover, 1986; Westberg, 1996; Rule et al., 2009). All of these programs, while enhancing students’ motivation and helping them learn group interaction process skills in invention, showed limited success in improving inventive abilities. However, Kuehn and Krockover (1986) and Rule et al. (2009) showed that their teaching the science of invention positively influenced the students’ inventive abilities. Unfortunately, these studies have been researched very little among secondary school students for teaching invention. The brief review of relevant literature on teaching invention shows finding ways to improve secondary school students’ inventive abilities for high-quality inventions is extremely important. This study was thus undertaken to ascertain if teaching invention by using the Invention Learning Approach would positively affect the inventive abilities of secondary students (mean age 15 years old). The specific research question is: Does manipulating the inventive learning approach influence students’ inventive abilities?

METHODOLOGY

Participants

This study used the strategy of convenience sampling to select participants from Nong Sung Samukkhiwittaya School in the Province of Mukdahan, Thailand. Twenty secondary students (mean age 15 years old) who showed interest and enrolled in an elective science course participated in this study (Male: 9, 45%; Female: 11, 55%). They have no previous experience in creating any inventions before this experiment. Approval was obtained from the school principal and the students’ parents for this study to be conducted.

Procedure

This study used the embedded experimental model of mixed methods research as shown in Figure 1. The mixed methods model is characterized as having qualitative data embedded within an experimental design (Creswell and Plano Clark, 2007). This study embedded the qualitative data during the interventions as well as in follow-up in-depth interviews after each quantitative creative invention performance test. This design denoted the intertwined relationship between qualitative and quantitative methods as a whole. In other words, a qualitative method could not stand by itself as an independent study, but served as a supplementary part for the quantitative methodology.

The total time to implement and collect data of the intervention was forty hours (over a period of20 weeks) during the second semester of the 2013 academic year. The experiment was divided into three phases including pre-intervention, intervention, and post-intervention.

In Phase I: Pre-intervention, both quantitative and qualitative data were gathered to identify students’ inventive abilities. This was accomplished by using the Creative Invention Performance Assessment (CIPA) instrument (pre-test).In order to explain and extend the quantitative findings, narrative data from the follow-up interviews with all students were collected after the analysis of test scores. To evaluate inventive abilities in the pretest and posttest,

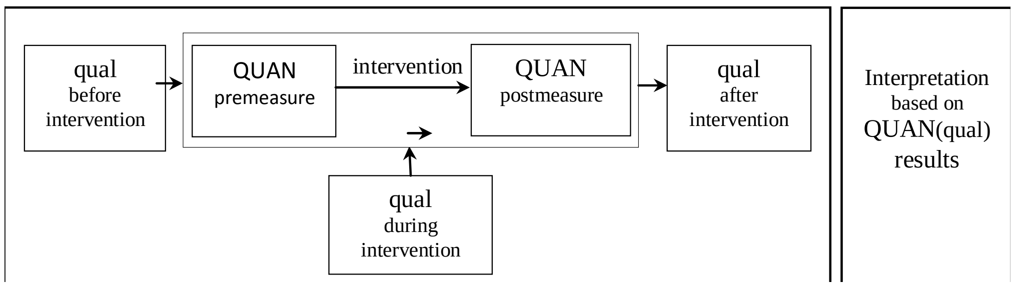

Figure 1. The embedded design: embedded experimental model of mixed methods research.

the participants were assigned to invent products in 4 h by using materials that were prepared by the researchers. Three experts, who have experience in graded inventions (see Instruments), graded the pretest and posttest. Follow-up in-depth interviews were conducted with all the participants after the quantitative data collection.

In Phase II: Intervention, the researchers implemented the learning activities (eight lesson plans) by using the Invention Learning Approach in the elective science course. The course involved application of the scientific method to scientifically invent projects. The main requirement of this course was to complete invention projects. Abundant qualitative data were collected through video-taping the intervention period, researcher's observation and field notes, informal interviews, and participants' written work. The strategy of content analysis of qualitative data (Henwood and Pidgeon, 1994; Lyons and Coyle, 2007; Boeije, 2010) was used to generate themes with the purpose of explaining and supplementing the quantitative data of the posttest. Data triangulation was implemented (Lincoln and Guba, 1985); while using the different sources to gather data: informal interviews, the researchers' documented observations of the students' actions and statements, students' portfolios, students' invention logbooks, and students' written work.

In Phase III: Post-intervention, data collection processes were similar to Phase I; both quantitative data from the post-test and qualitative data from the follow-up interviews with participants were gathered. However, the interview questions shifted focus to highlight the changes in the participants' performance in the effectiveness of the intervention. The interviews assisted in identifying whether the participants made progress throughout the intervention and what changes occurred within their performance. The rationale of this design approach was that quantitative data gauged exactly what problems and weaknesses existed in students' inventive abilities.

Materials

The Invention Learning Approach

This Invention Learning Approach was a credit-bearing elective science course offered by Nong Sung Samukkhiwittaya School. We attempted to develop an elective science course that was in accordance with Shlesinger's (1982, 1987a) approach of using step-by-step inventor approach programs. The researchers also developed this approach based on the in-depth interviewing of 10 Thai inventors and field studies of three Thai "Best Practice Schools" in teaching and learning invention. All stages of the approach attempted to motivate students and enhance their abilities to create new inventions, especially in the context of science. This learning approach, based on the idea of Constructionism allows students to learn about a subject by 'learning-by-designing' and 'learning-by-making', guides teachers as well as the schools (Papert, 1993). Constuctionism is meaningful and transferable learning in which students are given opportunities to construct inventions that answer a perceived need, using technology, improving the students' inventive abilities, and preparing them to become good inventors in the future. Students can develop their knowledge by making their own inventions (Westberg, 1996; Rule et al., 2009). The Invention Learning Approach contains seven stages:

Problem identifying to choose topics/products: Students have to find problems needing a solution. This stage teaches students how to listen for complaints and to recognize inconvenient situations for people in the real world to choose their topics. A good invention starts with an idea for something that may make people's lives easier or more efficient.

Searching for data/resources: Students collect as much data as possible related to the problem area in order to solve the problem. They must find out if their idea for an invention is original. They need to do research in magazines, catalogs, and on the Internet. They cannot invent products that have already been invented.

Imagining: Students use imagination or creative thinking techniques such as brainstorming or lateral thinking to solve the problem.

Designing/planning: Students prepare a model of their inventions to plan good forms and structures. They also prepare materials for the products based on the prototype. By doing this, students can be reassured that their products' plan/design is correct, thus increasing the likelihood that their invention will work. Their drawing does not have to be perfect, but it should be adequate for them to use to build a working product.

Creating inventions: Students create their products based on their prototypes or plans for their inventions by using the materials they have prepared in the *Designing/planning* stage.

Implementing: Students test their own inventions. The students should test their inventions several times in as real a situation as possible. Students should be made aware that the inventions might not work the first time.

Adjusting inventions: After the *Implementing* stage, students have to improve their inventions from problem identification. Repeat *Designing/planning, Creating inventions,* and *Implementing* stages until the inventions work.

In the learning activities by using the Invention Learning Approach, students were required to design inventions and maintain a learning portfolio that represented what they learned as they worked on their invention projects. Students began by defining and identifying their invention proposal projects. Then students submitted papers on

Table 1. Overview of eight lessons taught to students.

Lessons of the elective science course based on the invention learning approach
Lesson One: Science and Scientific Invention
Description: Students learn the definition of inventions and the relationship between science and invention called 'scientific invention', hear inventors' stories about their inventions, and see good examples of students' scientific inventions.
Lesson Two: Problem identifying to choose topics/products:
Description: This lesson teaches students how to listen for complaints and to recognize inconvenient situations for people in the real world to choose their topics. Students learn problem-finding techniques.
Lesson Three: Searching for data/resources
Description: Students collect as much scientific data and principles as possible related to the problem area in order to solve the problem. They must find out if their idea for an invention is original. They need to do research in magazines, catalogs, and on the Internet. They cannot invent products that have already been invented.
Lesson Four: Imagining
Description: Students use imagination or creative thinking techniques such as brainstorming or lateral thinking to solve the problem.
Lesson Five: Designing/planning
Description: Students sketch and experiment with designs and learn how to use assistant tools or grain technical assistance for making models or prototypes. They also prepare materials for the products based on the prototype. By doing this, students can be reassured that their products' plan/design is correct, thus increasing the likelihood that their invention will work. Their drawing does not have to be perfect, but it should be adequate for them to use to build a working product. Following good designing/planning techniques will save them a great deal of time and effort.
Lesson Six: Creating inventions
Description: Students create their products based on their prototypes or plans for their inventions by using the materials they have prepared.
Lesson Seven: Implementing and adjusting inventions
Description: Students test their own inventions. The students should test their inventions several times in as real a situation as possible. Students should be made aware that the inventions might not work the first time. After testing their inventions, students have to improve their inventions using problem identification.
Lesson Eight: Share and Protect Your Inventions
Description: Students learn about outlets for their inventions. They also learn how to protect their inventions by patenting them. Students present their invention to the public on 'The Invention Day'.

their project proposals, which showed their problem delineation and proposed solutions, to the class for discussions and critique sessions. Constant feedback from the other students and the teacher helped them improve their invention projects. The teacher guided, advised, and monitored the improvement of the students' projects from the problem identification and project design to the invention creating and testing. Table 1 shows an outline of eight lessons used in the elective science course based on the Invention Learning Approach.

Data collection and data analysis

The data in this study were used to answer the research question. Quantitative data collected from pre-test, and post-test were analyzed to answer the research question: Does manipulating the Invention Learning Approach influence students' inventive abilities? To identify whether the intervention was successful in improving students' inventive abilities levels within the intervention, nonparametric statistics: Wilcoxon signed-rank test was conducted. In addition to quantitative data, the method of content analysis of qualitative data collected from follow-up interviews explained and supplemented the initial quantitative results. Semi-structured interviews were used to reveal in-depth information related to the students' inventive abilities results. The method of content analysis (Zhang and Wildemuth, 2009) was utilized in order to categorize themes that appeared similar in content. This method of analysis revealed a number of themes relating to students' attitudes and opinions towards the invention learning experience. Each of these themes will now be discussed with examples from the database used as illustrations.

Instruments

The creative invention performance assessment (CIPA)

The Creative Invention Performance Assessment is a performance test simulating components of inventive abilities. The CIPA consists of 13 criteria of two dimensions including process abilities

(5 criteria) and product abilities (8 criteria).The researchers adapted the assessment form based on Besemer and Treffinger (1981) and Wongwanich (2004).This form is an authentic assessment using rubric scoring, analytic score. The student product assessment form of Besemer and Treffingerand Polson Enterprises is an assessment form used for assessing students' creative inventions including product quality, usefulness, feasibility, the safety of products, consumption/wastage, novelty, and resolution. This form can be used to assess any of the students' inventions. The performance assessment form of Wongwanich is also an authentic assessment used for assessing students' skills, including efficiency of the process and accuracy of the process. The 13 criteria with four-point rating scales developed by the researchers are listed with the judgments: very low, low, medium, or high for each item. Examples of the 13 criteria representing the process and product abilities are:

Process Issue

The student works with quality performance.
The student works safely.
The student manages his/her time effectively.

Product Issue

The invention shows a unique solution to a want or need.
The invention does not have any negative impact.
The invention is the simplest and most attractive it can be.
Descriptive analyses will be conducted to obtain mean and standard deviations for inventive abilities levels. The scores will be grouped on the following scale:

Very Low abilities: 1 through 1.50
Low abilities: 1.51 through 2.50
Medium abilities: 2.51 though 3.50
High abilities: 3.51 though 4.00

These scores are based on a cut-off system developed by the researchers. The total score will be identified as very low, low, medium, or high inventive abilities levels. Through review by 7 experts, content validity of CIPA was conducted.

The raters' report for the test indicated that the test measured what they purported to measure. The CIPA test was modified based on pilot test results with 20 students who possessed similar backgrounds and were required to have the same amount of an elective science course as those who participated in the present study. All of them have previous experience in developing their own inventions. The students had no problem understanding the assignment in the CIPA; the same CIPA materials were used in the test.

Three experts, who were formerly referees of the "Young Scientific Invention Competition", evaluated the students' inventive abilities using the CIPA in the pilot study. A Pearson correlation coefficient was calculated for the relationship among the three experts' evaluating the inventive abilities in the pilot study of the CIPA. A positive correlation was found between Expert 1 and Expert 2, Expert 1 and 3, $r = .748$, $p < .01$, $r = .751$, $p < .01$, respectively. Another positive correlation was found between Experts 2 and 3, $r = .694$, $p < .01$.

The relationship analysis shows that the experts' assessment of inventive abilities by using CIPA correlates significantly with each other.

Results

Descriptive Statistics and Levels of Inventive Abilities in Pre-Post Test Means, standard deviations and levels of participants' inventive abilities are presented in Table 2.

Table 2 shows that there is an increase in mean scores in every inventive abilities component. Similarly, the experts' judgment indicated that the post-test levels (Medium) of the students were also higher than pre-test levels in every inventive abilities component. As explained before, the students performed better in the post-test than in the pre-test (Very Low).

The comparison of students' inventive abilities in pre-post tests

Table 3 shows the result for nonparametric statistics: Wilcoxon signed-rank test indicated the post-test scores of students' inventive abilities were significantly higher than pre-test scores at the .01 level.

The comparison of pre-and post-test students' inventive abilities scores on individual growth

Figure 2 shows the difference of the inventive abilities scores of each student before and after learning through the Invention Learning Approach. As shown in Figure 2, students' inventive abilities were significantly improved after the intervention period. Students also had increased levels of inventive abilities after learning through the Invention Learning Approach.

Given the quantitative findings that the intervention displayed performance growth in inventive abilities over time, a qualitative analysis examined the underlying causes and potential undergirding evidence. Using a qualitative analysis on the narratives produced from the transcripts of the follow-up interviews, the findings seem to indicate that students improved in their performance during the intervention phase. The words expressed by the interview participants were a clear indication of their inventive abilities. The theme indicates that these students were able to plan and think creatively. Quotes from participants that support this theme:

I think learning in this course helped me a lot to create my quality product. I never knew before how to invent any inventions, but following this process it is not hard for me. I also had many creative ideas to create other inventions.

The results of the interview showed that 95.0% or 19 of participants agreed that the Invention Learning Approach was systematic and easy to use. For example, two students revealed the following:

I think it [Invention Learning Approach] worked well because it helped me to create my own invention, even though I had a hard time starting or finding my topic. It

Table 2. Means, standard deviations and levels of inventive abilities in pre-post tests.

Inventive abilities components	Full score	Pretest			Posttest		
		$\bar{X}$	S.D.	Level	$\bar{X}$	S.D.	Level
Process abilities							
Quality of performance	4	1.34	0.54	Very Low	3.23	0.53	Medium
Time management	4	2.02	0.57	Low	3.65	0.64	High
The development plan	4	1.30	0.49	Very Low	3.20	0.55	Medium
Safety at work	4	1.36	0.43	Very Low	3.20	0.36	Medium
Depletion of resources	4	1.36	0.57	Very Low	3.44	0.60	Medium
Total	4	1.41	0.45	Very Low	3.24	0.51	Medium
Product abilities							
Product quality	4	1.30	0.44	Very Low	3.16	0.56	Medium
Usefulness	4	1.99	0.22	Low	2.80	0.41	Medium
Feasibility	4	1.25	0.55	Very Low	3.03	0.60	Medium
Product safety	4	2.00	0.00	Low	3.40	0.68	Medium
Consumption/wastage	4	1.18	0.44	Very Low	3.11	0.39	Medium
Novelty	4	1.20	0.36	Very Low	2.92	0.59	Medium
Resolution	4	1.19	0.43	Very Low	2.88	0.57	Medium
Elaboration	4	1.89	0.37	Low	3.23	0.48	Medium
Total	4	1.46	0.41	Very Low	3.15	0.54	Medium

Table 3. The comparison of students' inventive abilities in pre-post tests.

Inventive abilities	N	Mean rank	Sum of ranks	Z
Negative ranks	0	.00	.00	3.921**
Positive ranks	20	10.50	210.00	

**at the .01 level of significance.

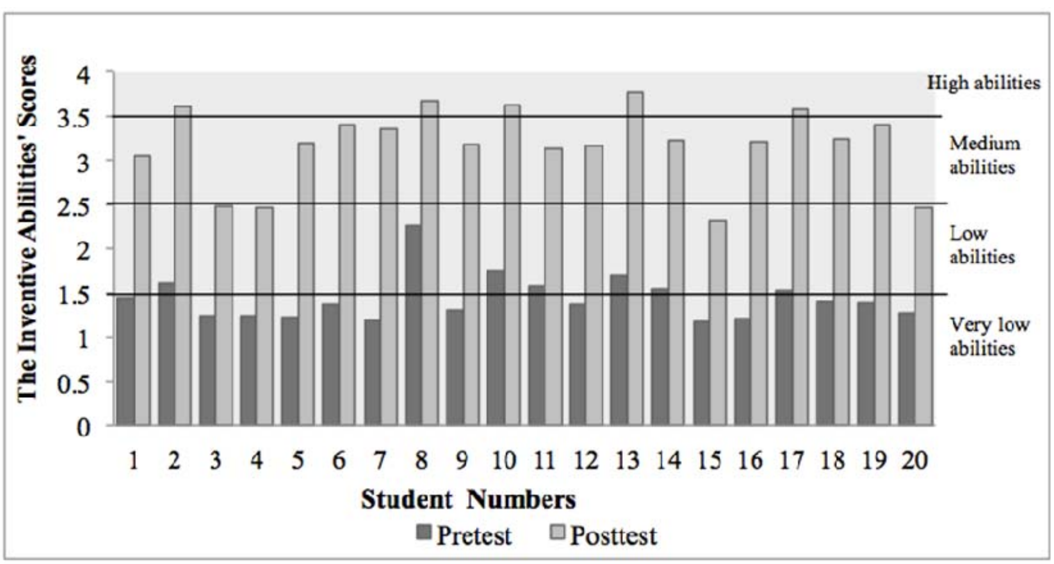

Figure 2. The comparison of pre- and post-test students' inventive abilities scores on individual growth.

was not difficult to do. The method taught us directly and systematically. It is not hard to use.

The other student also revealed:

I believe that this method [Invention Learning Approach] in this class is really an effective way for teaching how to invent inventions. Also I think for invention projects, a working project is fantastic because everyone has their own useful project that we could not get in another course.

Some students found that the Invention Learning Approach not only helped them to increase their inventive abilities, but also increased their levels of self-esteem and self-efficacy in inventive abilities. For example, one student revealed the following:

I did so badly in the pretest. I used to think my abilities about inventions were so bad. I was not an outgoing person. I do not always feel confident in myself to do any assignments. I have learned in this class. I learned a lot about how to work like an inventor. I felt that working on the invention projects and in learning groups helped to build up my self-esteem.

One student who attained one of the highest overall averages in inventive abilities also revealed:

By working on the invention project, the process in this course not only helped me to create my interesting inventions, but also made me comfortable. I feel good when learning in this course. It helped me to reduce my stress when I had difficult situations, especially when I produced original ideas. It gave me a chance to believe that I have the ability to do something like a great inventor did.

A result of the interviews found that the Invention Learning Approach also helped the participants generate more inventive ideas and inventions (100% participants said "Agree"). Like other inventors, the participants also know how to invent creative products. The students' responses revealed that learning through the Invention Learning Approach is helpful for enhancing inventive abilities to facilitate their creative performance. The participants seemed confident in what they had done and who they had become. On the other hand, 90.0% (n = 18) of the participants were determined to have had positive overall attitudes toward their inventive learning experience and 10.0% (n = 2) were regarded as being ambivalent. One student declared, "*I have really enjoyed this course, especially working on the invention projects. I feel it has given me an opportunity to invent a useful product.*"Yet another student reasoned, "*By working in this class, my stress and anxiety was reduced because I feel more free and comfortable to do my own job than other subjects like Math or English. We just focus only in our invention projects. We don't worry about any exams.*"

DISCUSSION

The main question addressed in this study was whether the use of the Invention Learning Approach would improve inventive abilities. The quantitative data revealed that participants had significant growth in inventive abilities over intervention time, which was consistent with findings in previous invention studies (Shlesinger, 1980; Westberg, 1996; Roll, 2009). The post-test scores of students' inventive abilities were significantly higher than pre-test scores. This was because the students were allowed to focus on designing and inventing their own individual invention projects based on the idea of Constructionism that allows students to learn about a subject by 'learning-by-designing' and 'learning-by-making' (Papert, 1993). This finding is in agreement with Westberg's (1996) findings, which showed that the students who received instruction in the inventing process developed a significantly greater number of inventions than students who received only an introduction. Additionally, this research illustrated the fact that the Invention Learning Approach based on Constructionism can be a powerful starting point in developing learning environments and technology. According to the learning outcomes, it is suitable to teach students with the Invention Learning Approach because this learning approach provides them with an opportunity to plan, design, conduct, and invent their own interesting projects. The quantitative findings were supported by the qualitative analysis. The qualitative findings portrayed the participants' viewpoints and experiences with respect to how the Invention Learning Approach assisted with their inventive thinking.

Conclusion

This study outlines an approach to teaching invention. The aim of the research was to present and prove the new concept of the Invention Learning Approach. As defined in this paper, the Invention Learning Approach is a specific learning approach that supports invention discovery via knowledge creation, adaptation, and exploits. Thus, the question regarding the nature of knowledge behind inventions becomes essential.

To conclude, both qualitative and quantitative results indicated that the students developed their inventive abilities during the elective science course by using the Invention Learning Approach. This study's Invention Learning Approach can be further extended to other courses and subjects. It is proven by this research that students' inventive abilities can be improved. In the future, research can be conducted to understand other aspects of learning, such as creative thinking, cooperative learning, and so forth in the context of invention learning. Additionally, we hope this research has provided some fundamental understanding for future research.

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Conflict of Interests

The author(s) have not declared any conflict of interests.

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