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Teaching science through technology: a confluence of knowledge, design and construction

Kuang-Chao Yu, Kuen-Yi Lin & Kuo-Feng Hung

National Taiwan Normal University
Taipei, Taiwan

ABSTRACT: The relationship between students' technological performance and their use of science knowledge, design skills and construction skills in a technology project, is examined in this article. The study was conducted in a classroom of 33 seventh-graders as they undertook a 16-hour water rocket building project. Analysed data reveal that hands-on practice can be effective in integrating students' science knowledge, design skills and construction skills. This technological practice can provide a context for introducing science concepts and to demonstrate that science is relevant and socially important. Also, as the science concepts to be developed are explicit, their design and construction skills enable them to apply their science knowledge.

INTRODUCTION

Science should be taught along with technology. Traditionally, the school curriculum has been organised largely on the basis that material should be separated into distinct subjects. Although there has been an increased emphasis on technology activities in science classrooms, these activities generally focus upon revalidating known scientific laws and principles but not on solving practical problems. On the contrary, in many technology classrooms, technology activity has been strong in practice but weak in science theory [1-3]. As a result, students would have great difficulty in recognising the relationship between science and technology.

The idea of integrating science and technology has gained significant attention as a plausible way to develop a more relevant approach to teaching and learning [4-6]. During the past decade, technology teachers have capitalised on the interest and motivation that technology problem-solving activities provide. For science teachers, technology problem-solving activities were used also to provide a practical and meaningful context. This idea is especially robust when the solution to a technology problem depends upon science and technology knowledge. As Goodlad noted, the understanding of concepts, rather than possessing the facts, gave students the intellectual power to attack unfamiliar problems and enabled them to grasp intuitively the relationship of new phenomena not previously encountered [7]. Technology practice embodies the actions of investigation, ideation, construction and evaluation, which can help learners to integrate their knowledge in ways that enable them to compartmentalise and organise their thinking [8][9]. In other words, learning technology is not merely the study of operation, but also the study of cognition, especially science knowledge. In fact, the thought of a straightforward path from science knowledge to a technological product sometimes functions as a paradigm in the classroom for the philosophy of technology education [10].

Technology is concerned with what can, and should, be designed, made and developed using science knowledge to satisfy human need. The concern for making science relevant has increased the interest in studying science in meaningful contexts, technology being one of these [11]. Some processes most used in technology classrooms are invention, innovation, problem-solving and design. For instance, the Department of Education in the United Kingdom indicated that technology capability requires students to combine their designing and construction skills with science and technology knowledge, to design and make products [12]. Technology capability is dependent upon a combination of ability and motivation that transcends understanding and enables creative development [13].

The idea of combining science and design in classrooms has recently received wide attention. Numerous curricula use design as a vehicle to support the learning of science, while some have chosen to use science as a resource to be used in design [14]. Design is constructive, concerned with how things ought to be, while science is analytic, concerned with how things are. Design is often used to tackle unstructured problems that require an individual to come up with solutions using a wide variety of materials and science and technology knowledge [15]. In this case, design is generally characterised by attempts to solve ill-defined problems based on an understanding of science. The design process also provides an opportunity to use constructive pedagogical practice to engage students in their own learning. As a pedagogical strategy, design activity has great potential to assist students in integrating learning from language, the arts, mathematics and science [16]. The design process model proposed by Hacker and Burghardt suggested that design should include the following steps:

1. clarify design specifications and constraints;
2. research and investigate the problem;
3. generate alternative designs;
4. choose and justify the optimal design;
5. develop a prototype;
6. test and evaluate the design solution;
7. redesign the solution with modifications; and
8. communicate the achieved design [17].

Consequently, some form of technological capability during the design is required to produce better solutions. In this sense, the design process guides problem-solving in technology education just as the inquiry method guides science education [18]. All this indicates that students can use the design process to apply knowledge of science in a given situation to describe or interpret phenomena scientifically and predict changes [19].

RESEARCH QUESTIONS

This article reports on a study of the influence on technological practice of students' understanding of science knowledge, design skills and construction skills. While this study focuses on a science and technology project called *water rocket building*, which deals with technical drawing, different sources of application and structural integrity, it was structured around a design goal chosen to be interesting and challenging to the participants.

The specific questions framing this study are: 1) How do students perceive these factors (science knowledge, design skills and construction skills) as contributing to successful technology practice; and 2) How do these factors act and interact?

Science knowledge in this article is defined as knowledge where the context is assessed by the statement written in the student's portfolio. *Design skills* are the ability to implement the steps of the design process in solving science-related design problems. *Construction skills* are the ability to complete the practical works of a water rocket.

METHOD

Participants

Thirty-three subjects took part in this study (13 female and 20 male), from a Taiwan junior high school seventh grade in the 2007-2008 school year. The students were enrolled in a four-week (four hours in each week) programme of science and technology at the junior high school in an urban area, and were above-average achievers when compared with other same-aged learners. The teacher had three years' experience teaching full-time. The teacher held a BEd in technology education with a minor in mathematics. He was also certified to teach secondary technology education, science and mathematics.

Procedures

To begin the study, subjects were asked in the first week to review the content of the on-line learning system developed by the researchers, and this was followed immediately by a class lecture and demonstration on the process of designing a water rocket. This was to help participants learn and integrate the science and technology knowledge before building the rockets. The subjects were then asked to build five water rockets in the following three weeks; one in the second week, and two in the third and fourth weeks. The reason for building just one rocket in the second week was to allow the students more time in becoming familiar with the tools and materials.

For each rocket built, a portfolio was required in which the subject recorded the science knowledge used, the design process and problems encountered, and the level of construction skills. The learning portfolio provides researchers with participants' learning and design processes. The data in the five portfolios from each participant were then analysed, using Pearson correlation and regression analysis, to examine the relationship between the practice performance (the flying distance of the water rocket) and the factors of science knowledge, design skills and construction skills.

The On-line Learning System

In this study, science and technology was the basis for the water rocket building project. An on-line learning system was developed for the students to learn science and technology knowledge, as Amabile urged for designing a technological product [20]. The on-line learning system consists of several categories, including teaching modules, assessments, virtual experiments and inquiry experiments. The fundamental perspective of this on-line learning system is aimed at providing diversified learning channels that furnish teachers with various innovative teaching methods to facilitate learning science and technology. Further, it attempts to cultivate independent learning by students so as to possess proper scientific, as well as technological knowledge and, hence, better adapt to future society. To help the student in learning require appropriate knowledge, the on-line learning system provides two learning knowledge units: 1) science and technology concepts, which provides students with related knowledge and concepts; 2) online simulations unit, which requires students to integrate the concepts learned from the science and technology area through an on-line simulation for the purpose of integrating the science and technology knowledge. Students, therefore, can manipulate the learning gained from the science and technology unit to create a virtual product in this simulation environment. After completing the learning on the Web, every student must undertake a water rocket building project by following a proper design process.

The Water Rocket Project

When making the water rockets, students were asked to describe and analyse problems encountered in flying the rocket, and to utilise science and technology knowledge learned from the on-line learning system to solve the problems. This water rocket building project provided a context in which the students could apply their understanding of what they had learned from the on-line learning system. The goal of this project was to promote the development of skills that may be useful in design situations involving science. In other words, a project was planned and implemented in which technology practice integrated the study of science to enable students to design and explain a useful artefact.

Instrument

To analyse students’ thinking and design processes, a learning portfolio was designed, based on the Hacker and Burghardt model, and it was used to collect data [17]. All subjects were asked to build five water rockets in a three-week period, and five learning portfolios from each subject were collected and analysed. The portfolio includes three sections:

1. *Science knowledge*: students were asked to describe the relevant science knowledge that they brought to the task of making the five water rockets. This included 20 open-ended questions related to the concepts of air resistance, centre of gravity, momentum and pressure. The purpose of this test was to assess whether the students had some of the science knowledge relevant to building the water rockets. The concepts evaluated in this section of the portfolio were scored with unequal weights, ranging from 0 to 2 points, with two points given to the correct answer; one point given to an unclear answer; and 0 points given to a wrong answer. Every student received science knowledge scores, which were computed to a percentile for each of the five portfolios. The reliability was tested by two science and technology teachers from a junior high school and α=0.698.
2. *Design skills*: students were asked to describe the design and the problems encountered after flying each water rocket, which would be used as a reference for the improvement of the next rocket. In this section, three open-ended questions were asked: a) *what* are the flying problems; b) *why* would these problems happen; and c) *how* to make a new design to solve the problems. The answers to the three questions were scored with unequal weights, ranging from 1 to 5 points, depending on the student’s description. To assess the reliability of the score of this design process, Cronbach’s alpha test was used to take the three main questions (what, why and how) as the independent items. The reliability was conducted by two science and technology teachers from a junior high school and α=0.728.
3. *Construction skills*: for each water rocket built, a seven-item checklist focusing on the skills demonstrated was used to examine the performance levels of the students’ construction skills. In this section of the portfolio, the scores of the performance levels were recorded by the teacher, with one point given for worst, two points given for adequate and three points given for good in each of the items: a) Whether the edge of the water rocket is smooth; b) Whether the cutting line is straight and easy to combine; c) Whether the cutting is on the widest part of the bottle; d) Whether the bottle is stuck smoothly; e) Whether the tape is stuck tightly and firmly; f) Whether the joint of the bottle is straight; and g) Whether the tail is stuck tightly and straight.

The aim of the study was the analysis of how students perceived the three factors (science knowledge, design skills and construction skills) as contributing to successful performance (flying distance), and how these factors acted and interacted. The approach taken was to look for correlations between the performance obtained for five rockets and those factors that assessed the subjects’ knowledge and context. If the knowledge developed during rocket building supported the improvement of design, it was expected that the integrated knowledge of the subjects would be more highly correlated with success on the flying task week after week.

RESULTS AND DISCUSSION

Practical Performance of the Water Rocket

On the second week of the project, the students seemed interested in building water rockets. They spent time practising their use of tools and thinking how to answer the questions in the portfolio. Very few students made use of the on-line learning system; almost all went directly to making the rockets. Only a few described how they were going to make the rocket and why they selected the material. However, all the students completed their first rocket.

On the third and fourth weeks, most of the students seemed energetic and motivated. Most of them appeared to have reviewed the content of the on-line learning system at home, and a lot of questions were raised in the classroom.

Table 1 shows the mean and the standard deviations of the flying distance for each week. There is a trend indicating that the distance increased every week. Also, a significant difference was found, using a paired sample test, between the weeks. These results demonstrate that students have gained experience from building the rockets, to integrate their science knowledge, design skills and construction skills to improve the performance of the rocket.

Table 1: Flying distance of the water rockets in each week.

	Minimum	Maximum	Mean	SD	*t* value
Week 2	0.00	54.60	11.02	10.57	
Week 3	6.70	71.55	25.16	14.77	3.55**
Week 4	10.15	75.80	37.07	19.84	3.11**

$^{**}p<0.01$

Note: *t* value indicates the *t*-test compared with the previous week

Results for Science Knowledge, Design Skills and Construction Skills

To know why the students' performance on launching a water rocket increased significantly, it was necessary to examine the growth of their science knowledge, design skills and construction skills during the three weeks. Data in Table 2 indicated that students improved on science knowledge, design skills and construction skills after they made five water rockets. A *t*-test was also computed on the week 2 scores versus week 3, and week 3 versus week 4. Students' recognition of science knowledge became mature in the last two weeks, and it could be the reason why students' rockets increased launch distances.

The same situation was found on students' construction skills in the last two weeks. However, there was no significant increase in design skills in the fourth week. This meant that better science knowledge and construction skills, coupled with stable design skills, increased the flying distances. It also meant that science knowledge and construction skills played an important role on flying distances during the last week. Once the students knew how to use their design skills after considering their problems, the students performed well on design. In this way, science knowledge and construction skills affected flying distances greatly during the last week. Students understood their design problems after coming across difficulties, so they scored steadily on design skills. Therefore, the flying distance depended on how well use was made of science knowledge and construction skills.

Table 2: The performance of science knowledge, design skills and construction skills in each week.

Weeks	Science Knowledge		Design Skills		Construction Skills	
	M/SD	*t* value	M/SD	*t* value	M/SD	*t* value
Week 2	43.82/14.51	-	N/A	-	14.50/2.53	-
Week 3	59.23/17.62	3.84*	11.54/2.09	-	15.92/1.82	2.55*
Week 4	73.85/21.43	2.97*	12.18/2.24	1.14	17.83/2.20	3.75*

$^{*}p<0.05$

Note: *t* value indicates the *t*-test comparison with the previous week

When examining the data in Table 3, it was found that, in the second week, students' performance was not related to their science knowledge as measured from their first portfolios. However, the relationship with construction skills reached a significance level of 0.05 (r=0.404). This indicates that construction skills in building a water rocket for the first time is more influential compared with science knowledge. Their first launch experience might affect flying distance, so construction skills would be the key factor. Hence, how well students knew science did not correlate significantly with the launch distances in the second week (r=0.125) though it might correlate with insufficient science knowledge (M=43.82).

Table 3: Correlation matrix of technological practice and science knowledge, design skills and construction skills for each week.

Weeks	Science Knowledge	Design Skills	Construction Skills
Week 2	0.125	N/A	0.404*
Week 3	0.136	0.380*	0.319
Week 4	0.572**	0.364*	0.522**

$^{*}p<0.05$, $^{**}p<0.01$

In the third week, a Pearson correlation analysis showed that students' technological performance on the water rockets had a significant correlation (*r*=0.380) with their design abilities as measured from the second and third portfolios. Such a result stemmed from the idea that students' design skills may be a better indicator to predict students' performance in relatively higher cognitive tasks (e.g. application of knowledge), while they were building a water rocket. Even though students' science knowledge and construction skills advanced significantly, there was no significant correlation between these two factors. Obviously, the improvement of science knowledge and construction skills helps the students to increase the flying distances in the third week. But the main factors for increasing the flying distance in the third week was the experience of problem-solving and redesigning the water rocket.

In the fourth week, students' technological performance on the water rockets was related to their science knowledge (*r*=0.572), design skills (*r*=0.364) and construction skills (*r*=0.522) as measured from the fourth and fifth portfolio. The increased *redoing* time implies that researchers should consider how students used their knowledge and skills differed in each learning period. This indicates that well-organised science knowledge allows students to solve novel problems. Such well-organised knowledge requires students to integrate their contextual, conceptual and procedural knowledge in a domain. In this study, when students could not use science knowledge effectively, construction skills became the key factor related to flying distances. As long as students knew how to use science knowledge and became familiar with using construction skills, design skills were then related to flying distances. After the fourth week, these three factors were significantly related when the students used science knowledge, design skills and construction skills. This also indicated that science domain knowledge (science knowledge) and technological domain knowledge (construction skills) had both reached a standard level, with further assistance from procedural knowledge (design skills) to successfully complete a technological goal. Effective learning is needed to combine drill and practice with students' understanding and application of knowledge.

The Pearson correlation coefficients among science knowledge, design skills and construction skills in week 4 are presented in Table 4. The bi-variant relationships indicated that all of the variables were significantly correlated and the correlations were all less than 0.50. In this project, it became apparent that science knowledge, design skills and construction skills were all necessary to complete the project.

Table 4: Correlation analysis across science knowledge, design skills and construction skills in Week 4.

	Science Knowledge	Design Skills	Construction Skills
Science Concept	1		
Design Skills	0.432*	1	
Making Skills	0.377*	0.399*	1

* $p<0.05$

To further analyse how these three factors predict students' ability on technological tasks, a regression analysis was performed to check the effects of predicted variables on the technological tasks. The result showed two independent variables (science knowledge and construction skills) could predict a student's practical performance (F=10.870, $p<0.01$, R2=55.6), as shown in Table 5. In conclusion, after two weeks' learning, students' science knowledge and construction skills had the most influence over practical performance. One may question why design skills were not an important predictive factor. The reason may be that students usually dealt with design problems in the same way so that science knowledge and construction skills became more important factors.

Table 5: Regression analysis for Week 4.

	B	Std Error	*t*	Sig
(Constant)	-94.896	33.002	-2.875	0.008**
Science Knowledge	45.674	13.979	3.267	0.003**
Design Skills	0.449	1.340	0.335	0.740
Making Skills	5.131	2.027	2.531	0.018*

F=10.870, df=32, R=0.746, R2=55.6
* $p<0.05$, **$p<0.01$

CONCLUSIONS

This article reports on students' learning processes and sources of knowledge used in an integrated learning setting. The authors are aware that the sample of student is small and the findings may well be unique to that sample. The authors ask the reader to consider if the findings of this study have any relevance to their own situations and to consider if the results are credible.

In this project the learning of science was not an initial objective. However, as the project evolved, it became apparent that science understanding was necessary to build the water rocket. Technological activities can provide a context for introducing science concepts and demonstrating that science is relevant and socially important. Also, as long as the students are explicit about the science concepts to be developed, design and construction skills enable them to apply their science knowledge.

Science seeks to understand phenomena and technology seeks to harness innovation and design to utilise nature for a practical purpose. In the past, it has resulted in a craft orientation to the teaching of technology and a more academic approach to the teaching of science. The results of this study indicate that integrated technology projects offer considerable potential for students to learn science. It is important for the successful learning of science that students understand that it is centrally concerned with developing explanations. Students also need to understand that while science explains nature by making generalisations, technology is concerned with changing it to create unique solutions to solve problems.

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