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From Using to Learning: Educational Possibilities of 3D Printing in Technology Education through Design-Based Research

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Abstract

Digital fabrication technologies such as 3D printing are increasingly used in school education and are often associated with creative making. However, previous studies have pointed out the risk of superficial making, where students focus on visual outcomes rather than engaging in design reasoning. This study examines the educational potential of 3D printing by exploring how students conceptualize its role in relation to a contrasting fabrication method, woodworking. A design-based research (DBR) approach was employed in an open-ended problem-solving task combining woodworking and 3D printing with 177 first-year lower secondary students in a Japanese public school. Students freely selected materials and fabrication methods based on their design ideas. questionnaires, and open-ended reflections. Among 120 analysed cases, products were classified into functional and decorative groups based on the role of 3D-printed components. Quantitative results showed no significant differences in enjoyment or perceived difficulty between groups. However, the functional group demonstrated significantly higher awareness of the characteristics of 3D printing. Qualitative text analysis revealed that while the decorative group emphasized ease of use and appearance, the functional group more frequently referred to design considerations, complex geometries, and the complementary relationship between fabrication methods. These findings suggest that the educational value of 3D printing depends not merely on access to the technology, but on how it is positioned within design decision-making. Learning environments that juxtapose multiple fabrication methods can support learners in developing a more conceptually grounded understanding of materials, processes, and design.

Key Words: 3D Printing, Technology Education, Design-Based Research, Learning Design, Digital Fabrication

1 INTRODUCTION

In recent years, with the development of the Maker Movement and digital fabrication technologies, their use in educational settings has expanded (Halverson & Sheridan, 2014). In particular, 3D printing has been introduced early in school contexts and has been increasingly used across a wide range of subjects and learning contexts (Ford & Minshall, 2019). For example, integrating 3D printing into STEM project-based learning has been reported to enhance students' perceptions of creativity and problem-solving abilities (Ali Bicer et al., 2017).

While these studies highlight the educational potential of 3D printing, some challenges have also been identified. In school-based making activities, visually attractive artifacts tend to be highly valued, which may lead students' attention to be directed toward decorative features rather than functional performance. Blikstein (2013) described this tendency as the "keychain syndrome," in which learners' focus shifts away from design reasoning and consideration of technical principles and toward the production of appealing outputs.

This issue resonates strongly with long-standing discussions in technology education, where learning is conceptualized not as the completion of artifacts but as the process of judging what works in response to a design problem. From this perspective, design activity involves evaluating and selecting technical means—such as materials and fabrication processes—in relation to purposes and constraints (Williams, 2010; de Vries, 2005). These perspectives suggest that technology education offers a productive theoretical lens for addressing educational challenges associated with digital fabrication.

However, review studies on the educational use of 3D printing have highlighted its potential benefits, such as enhancing creativity, supporting problem solving, and enabling iterative prototyping. At the same time, its adoption in K–12 education remains limited, and the integration of 3D printing into educational systems has been identified as an important challenge (Ford & Minshall, 2019). Within this context, particular attention should be paid to how learners position 3D printing in relation to other materials and fabrication processes, especially how they understand it as a technical means within design decision-making.

Accordingly, this study situates 3D printing in relation to learners' prior experiences with manual fabrication, focusing in particular on woodworking as a contrasting example. An open-ended design-based problem-solving task combining woodworking and 3D printing was implemented. On this basis, the study explores how students conceptualize and articulate the advantages of 3D printing and examines differences in these framings from the perspectives of decorative and functional use. Specifically, this study addresses the following research questions:

(i) What aspects of 3D printing do students identify as advantageous when engaged in a problem-solving task that incorporates both woodworking and 3D printing?

(ii) Compared with students who use 3D printing primarily for decorative purposes, what kinds of design-related considerations characterize students who use 3D printing in a functional manner?

2 THEORETICAL BACKGROUND

2.1 Analytical Perspective of This Study

This study focuses on how students perceive the advantages of 3D printing in a learning task that combines 3D printing and woodworking. In particular, students' post-activity reflections are examined with attention to whether their use of 3D printing is framed primarily in decorative terms or in functional terms.

In technology education and design research, design activity has long been conceptualized as a process involving problem solving and judgment rather than merely the production of finished artifacts (Cross, 2001; Lewis, 2004; Williams, 2010). From this perspective, the educational significance of design lies in learners' engagement in judging what works in response to a given design problem. However, Vossoughi and Bevan (2014) have pointed out that making activities can sometimes be reduced to step-by-step, recipe-like construction, limiting opportunities for deeper engagement in design. This suggests that the structure of learning tasks and environments plays a critical role in shaping the quality of learners' engagement in design activity. Accordingly, investigating how students interpret the advantages of 3D printing as a digital fabrication technology provides an important lens for considering how such technologies are positioned within technology education.

2.2 Educational Characteristics of Digital Fabrication

3D printing is an additive manufacturing process in which objects are fabricated through the layer-by-layer deposition of material based on digital design data. This process allows relatively complex geometries to be realized and supports iterative modification of designs through changes to digital models (Gibson, Rosen, & Stucker, 2015).

In contrast, conventional fabrication methods such as woodworking are largely based on subtractive processes and involve different principles and constraints. Previous studies have examined the educational impact of 3D printing by comparing it with traditional fabrication methods. For example, Greenhalgh (2016) reported that, while 3D printing improved precision and craftsmanship, students perceived hand construction as more beneficial for supporting the design process. These findings suggest that different fabrication methods afford different forms of engagement in design activity.

Differences in material properties and fabrication processes shape both the possibilities and limitations of design and are therefore expected to influence learners' points of attention during design activity (Ashby, 2011; de Vries, 2005). From an educational perspective, engaging students with multiple fabrication methods can make these differences explicit and provide opportunities for learners to consider why particular materials and processes are appropriate for specific purposes. Furthermore, it is important to examine how learners interpret these differences and position them as technical means within their design decision-making.

2.3 Constructionist View of Learning

Papert (1980) proposed constructionism, which emphasizes that learners construct knowledge through the process of designing and making meaningful artifacts. From this viewpoint, making is not simply a means of producing an end product but serves as a medium through which ideas are externalized, examined, and reconstructed.

Research on design activity further suggests that learners engage in a reflective conversation with materials and representations such as sketches, models, and prototypes (Schön, 1983; Goldschmidt, 1991). These representations function as resources that support learners in inspecting, revising, and developing their ideas.

Grounded in this constructionist perspective, the present study does not attempt to directly measure students' internal understanding. Instead, it examines how students construe 3D printing as a technology by analyzing their final products and their post-activity responses.

3 RESEARCH DESIGN AND METHODS

This study adopted a design-based research (DBR) approach (Design-Based Research Collective, 2003) to examine students' learning in an open-ended problem-solving task that combined woodworking and 3D printing. The present study is positioned as an exploratory cycle within an initial implementation of a learning design that emphasizes comparison and selection among different fabrication methods. The findings are intended to inform subsequent refinement of learning design.

The study was conducted in one public lower secondary school in Japan. Participants were 177 first-year lower secondary students. All students followed the same instructional sequence and had no prior formal experience with 3D printing. Prior to the main task, students engaged in preparatory activities using small-scale tasks with restrictions on the number of materials and component sizes, through which they learned basic procedures for woodworking and 3D printing.

In the main task, students were asked to identify a problem in their everyday lives and to design and fabricate a product using appropriate materials and fabrication methods. The task was open-ended, and students were not restricted in their choice of materials or processes. They could use woodworking only or combine woodworking with 3D-printed parts according to their design ideas. Laminated wood and 3D-printed parts could be used without numerical limits. The task was implemented over twelve class periods (five periods for planning and design, and seven periods for fabrication).

After completion of the task, students' final products were collected, and a post-task questionnaire and open-ended written reflections were administered. Both the questionnaire and written responses were completed anonymously during class time. Students were informed that their responses would be used only for research purposes, and participation was voluntary.

For the present analyses, 120 students who provided complete sets of final products, questionnaire responses, and written reflections were included.

The questionnaire consisted of items rated on a four-point response scale (4 = strongly agree, 3 = somewhat agree, 2 = somewhat disagree, 1 = strongly disagree) addressing enjoyment of the task, perceived difficulty, awareness of the characteristics of 3D printing, understanding of material properties, understanding of fabrication processes, changes in perspectives on materials and processes, and selection of materials and processes according to purpose, and these items were developed based on the instructional goals of the unit and relevant prior research in technology education.

The items included statements such as: “I enjoyed the free-making activity aimed at solving a problem,” “I found the activity difficult,” “I was able to design and create parts by considering the characteristics of the 3D printer,” “I was able to understand the differences in properties between materials such as wood and plastics,” “I was able to understand the differences between fabrication methods such as woodworking and 3D printing,” “Through the activity, my way of thinking about materials and fabrication methods in everyday life changed,” and “If I had another opportunity for free making, I would be able to select materials and fabrication methods according to my purpose.”

Open-ended responses were collected using two prompts: “What do you think are the advantages of 3D printing? Please describe freely.” and “Please write your impressions of the lesson freely.” Students were asked to respond freely without a fixed template.

Open-ended responses were written in Japanese. Morphological analysis and frequency analysis were conducted using KH Coder (Higuchi, 2016), focusing on content words such as nouns, verbs, and adjectives. Function words were excluded. After consolidating semantically similar word forms, the authors examined the contexts in which frequent words appeared and interpreted their meanings.

Analyses were conducted on the original Japanese data, and key words and expressions were translated into English for reporting. Final products were classified into a functional group and a decorative group based on the role of 3D-printed parts within the products. Two authors conducted the classification independently and discussed discrepancies until agreement was reached. Questionnaire data were summarized using descriptive statistics, and group differences were examined using Welch’s independent-samples t-test.

No generative AI tools were used to produce the text or conduct the analysis in this study. Generative AI was used only for minor language refinement, including translation support. All interpretations are those of the authors.

4 RESULTS

4.1 Classification of Final Products and Questionnaire Results

Students' final products created in the main task were analysed with a focus on how 3D-printed parts were used in relation to wooden components. Based on the role played by 3D-printed parts within each product, the products were classified into two groups based on the role of 3D-printed parts: the Functional group and the Decorative group.

Products in the functional group included 3D-printed parts that served functional roles, such as hooks or storage components designed for specific objects or shapes, with the aim of improving usability or performance. In these products, woodworking and 3D printing were combined to address particular functional requirements.

In contrast, products in the decorative group included 3D-printed parts with primarily decorative or aesthetic qualities, such as name plates or star-shaped charms. In these cases, 3D printing was used mainly to enhance the appearance of the product and did not play a functional role. Representative examples of products from each group are shown in Figure 1.

Figure 1

Representative examples of products in the functional and decorative groups

These examples illustrate how 3D-printed parts were integrated with wooden components, highlighting the distinction between functional uses and decorative applications.

Of the 120 students whose final products were analysed, 73 were classified into the functional group and 30 into the decorative group. The remaining 17 students used woodworking only and did not incorporate 3D printing; therefore, they were excluded from group-comparison analyses.

A post-task questionnaire was administered to examine students' perceptions of the task.

Across all students (N = 120), mean scores for all questionnaire items exceeded the midpoint (2.5), indicating generally positive perceptions of the task. The mean score for enjoyment was 3.58 (SD = 0.57), and the mean score for perceived difficulty was 3.11 (SD = 0.66). The mean score for awareness of the characteristics of 3D printing was 2.88 (SD = 0.85). Mean scores for understanding of material properties and understanding of fabrication processes were 2.98 (SD =

0.72) and 3.10 (SD = 0.74), respectively. The mean score for changes in perspectives on materials and processes was 3.18 (SD = 0.66), and the mean score for selection of materials and processes according to purpose was 3.29 (SD = 0.73).

Group comparisons between the functional and decorative groups were conducted using Welch's independent-samples t-test (Table 1). No significant differences were found for enjoyment or perceived difficulty. However, the functional group showed significantly higher scores on awareness of the characteristics of 3D printing than the decorative group (t = 2.53, p = .014, d = 0.58).

Table 1

Comparison of the functional and decorative groups on questionnaire items

Item (short description)	Functional group (n=73)	Decorative group (n=30)	*t*	*p*	*d*
Enjoyment	3.63 (0.54)	3.43 (0.63)	1.51	.139	0.35
Difficulty	3.15 (0.66)	3.03 (0.67)	0.81	.420	0.18
Considered features of 3D printer	3.01 (0.81)	2.53 (0.90)	2.53	.014*	0.58
Understanding material properties	3.00 (0.71)	2.87 (0.73)	0.85	.399	0.19
Understanding fabrication processes	3.15 (0.72)	2.93 (0.78)	1.31	.197	0.29
Change in perspectives	3.15 (0.66)	3.10 (0.71)	0.34	.739	0.08
Ability to select materials and processes	3.40 (0.66)	3.13 (0.78)	1.63	.109	0.38

Note: Values are *M* with *SD* in parentheses. Group differences were examined using independent-samples Welch's *t*-test. $p < .05$.

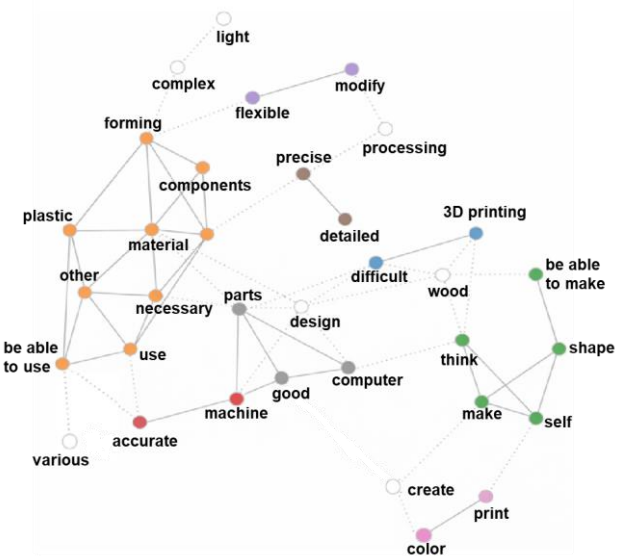
4.2 Co-occurrence Network Analysis of Students' Responses on the Advantages of 3D Printing

To examine how students perceived the advantages of 3D printing, a co-occurrence network analysis was conducted on open-ended responses collected after the task (Figure 2).

In the network, nodes represent words and links indicate co-occurrence relationships between words based on their tendency to appear together in the responses. In this study, node size does not represent frequency; instead, the network focuses on structural relationships among words. The network reveals several interconnected clusters of words, reflecting different ways in which students interpreted the advantages of 3D printing.

Figure 2

Co-occurrence network of students' perceptions of 3D printing



One cluster centers on words such as "make," "shape," "self," "create," "print," and "color," indicating that students perceived 3D printing as a means of giving form to their own ideas and supporting visual expression.

Another cluster includes terms such as "plastic," "material," "components," "parts," and "forming," suggesting that students understood 3D printing in relation to materials, parts production, and fabrication processes.

A further cluster is organized around words such as "precise," "detailed," "accurate," and "machine," indicating that students recognized the precision and mechanical characteristics of 3D printing.

In addition, words such as "design," "computer," "3D printing," and "difficult" form a cluster associated with digital design processes, suggesting that students perceived 3D printing as a technology connected to design and to the production of forms that are difficult to realize otherwise.

Taken together, these clusters indicate that students perceived the advantages of 3D printing not only in terms of appearance, but also in relation to fabrication, precision, and digital design processes.

4.3 Comparison of Characteristic Words Between Groups

To further examine the differences between the functional group and the decorative group, characteristic words were extracted using KH Coder. Characteristic words are those that appear more frequently in a particular group compared to others and are identified based on association measures such as the Jaccard coefficient (Higuchi, 2017). The values shown in Table 2 indicate the degree to which each word is characteristic of a given group in comparison to the other group.

Table 2

Characteristic words in the decorative and functional groups (association scores)

Functional group (n=73)	Score	Decorative group (n=30)	Score
shape	0.297	make	0.209
make	0.257	self	0.133
wood	0.143	be able to	0.133
think	0.130	easy	0.098
computer	0.071	color	0.083
flexible	0.062	3D printing	0.079
design	0.062	design	0.061
complex	0.062	decide	0.061
light	0.052	hand	0.061
parts	0.041	like	0.057

Note. Scores indicate the degree to which each word is characteristic of the respective group based on association measures (e.g., Jaccard coefficient).

Differences were observed in the types of words appearing in each group. In both groups, “make” was a prominent word. In the decorative group, words such as “easy,” “color,” and “self” were extracted as characteristic words, indicating that students referred to the usability of 3D printing as well as personal preferences and visual appearance.

In contrast, the functional group included words such as “shape,” “wood,” “computer,” “design,” “complex,” and “parts.” These words suggest that students referred to aspects related to materials, digital tools, design processes, and geometric forms. In particular, the appearance of the word “wood” indicates that students referred to the relationship between 3D printing and other materials, while the word “complex” suggests that 3D printing was understood in relation to the production of complex shapes.

These tendencies were also reflected in students' written responses. For example:

- "A 3D printer is very useful because it can solve problems that cannot be solved with wood alone, and I think it will be useful in the future."
- "It is possible to make small parts or round parts that are difficult to make with wood."

In addition, some students referred to characteristics of digital design and machine-based fabrication:

- "If I design what I have in mind, I can make it exactly as designed."
- "It is difficult to make something exactly as intended with wood, but with a 3D printer, the machine will make it as long as the design is correct."

Overall, these results indicate that students in the functional group tended to refer more to materials, design processes, and forms, whereas students in the decorative group emphasized usability and visual aspects.

In addition, some students mentioned changes in how they viewed materials and fabrication methods in everyday life, such as noticing that materials and processes are selected according to purpose or becoming more aware of the effort and ingenuity involved in making everyday products.

5 DISCUSSION

This study examined students' learning in an open-ended problem-solving task that combined woodworking and 3D printing, using both quantitative and qualitative data. No significant differences were found between the functional and decorative groups in self-reported understanding of material properties or fabrication processes. However, students in the functional group reported significantly higher awareness of the characteristics of 3D printing during design. In addition, analysis of written responses indicated that students in the functional group tended to reflect on their design and fabrication processes with attention to the characteristics of different materials and processes.

These findings can be interpreted from the perspective of constructionism (Papert, 1980). Papert argued that learning is not simply a matter of constructing artifacts but involves constructing ideas and concepts through the act of construction. Students in the functional group did not treat 3D printing merely as a means of producing shapes; rather, they engaged in design by considering the properties and constraints of fabrication methods through comparison with woodworking. This suggests that their activity involved not only assembling products but also developing conceptual understanding of fabrication processes.

At the same time, learning with digital fabrication does not automatically lead to such conceptual understanding. Blikstein (2013) warned that the accessibility of digital fabrication may cause learners' activity to converge on operation and output, resulting in superficial making that lacks design judgment or engagement with technical principles. The tendencies observed in the decorative group are consistent with this concern, as 3D printing appeared to be used mainly as a means of enhancing appearance.

An important implication of this study is that, even within the same learning environment, students may frame 3D printing in qualitatively different ways—as a functional design resource or as a decorative addition. While combining woodworking and 3D printing can create conditions that open possibilities for conceptually rich construction, it does not guarantee that all students will engage in such learning.

Woodworking and 3D printing embody fundamentally different relationships between design and fabrication. In woodworking, students interact directly with material and can make situational adjustments during cutting and assembly. Larger components and structural elements are relatively easy to handle, and design and fabrication often proceed in an intertwined manner. In contrast, 3D printing involves automated fabrication based on digital design data, requiring shapes and dimensions to be explicitly specified in advance. This enables high-fidelity reproduction and the creation of complex geometries and small parts that are difficult to realize through woodworking.

Students in the functional group referred to features such as "small parts that are difficult to make with wood" and "being able to make exactly what was designed," indicating awareness of these differences. The significantly higher scores for awareness of 3D printing characteristics further support the presence of such understanding among some students.

From a design-based research perspective, these findings suggest that the educational value of 3D printing arises not simply from providing opportunities to use the technology, but from positioning it within learning designs that foreground its technical characteristics and principles (Brown, 1992; Design-Based Research Collective, 2003). In other words, what matters is not whether students use 3D printing, but how it is positioned in relation to other materials and processes.

In technology education, this implies the importance of addressing not only operational skills, but also additive manufacturing processes, material behavior, and the relationship between digital design and physical fabrication. When such knowledge is integrated into instruction and juxtaposed with other fabrication methods such as woodworking, students may begin to view fabrication technologies not as tools to be used uncritically, but as technologies that should be selected and justified according to purpose.

This perspective is relevant beyond 3D printing, extending to emerging technologies such as laser cutters and artificial intelligence, which can produce sophisticated outcomes without requiring users to understand underlying mechanisms. Future learning design should incorporate prompts that encourage comparison among technologies and activities that require students to articulate

reasons for their choices, thereby supporting a gradual shift from decorative to functional framings.

This study has several limitations. In addition to being conducted in a single school and grade level, the classification of products and interpretation of written responses involved researcher judgment. Furthermore, the questionnaire items were developed specifically for this study and were not based on a standardized scale; therefore, issues related to the validity and reliability of the measurements remain. Future research should address these limitations by examining the findings in other educational contexts and by developing more robust and validated measurement instruments.

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