

The relation between students' creativity and technological knowledge in cross-curricular technology and design projects

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Abstract

This study presents an analysis of how creativity in students work is related to the role of the key conceptual technological knowledge in four different cross-curricular technology and design projects in Norwegian primary and lower secondary school. All of the school projects examined were intended to be open-ended providing students with opportunities to be creative and develop their own solutions to the given task. The processes in the groups and the outcomes of the groups' work are analyzed with regards to technological knowledge and how this relates to the students' creativity in terms of producing genuine solutions. The analysis shows that in some of the projects the variety of solutions produced by the students is limited. In these student groups the solutions and procedures bear a high degree of resemblance to each other. The findings suggest that students' limited conceptual technological knowledge constrains their ability to be creative and to produce genuine solutions. The findings also suggest that the projects showing less student creativity tend to be more controlled by the teacher and less open-ended than presupposed. A suggestion based on the findings is that the key conceptual technological content should be identified and communicated by the teacher prior to the project start. Discussing explicitly and exploring concepts and principles with the students before or during the project period will enhance their possibility to be more creative.

Introduction; basics of artifacts

A characteristic of the conceptual aspects of artifacts is their function. Artifacts are developed for a reason, they are intended to perform and fulfill a human need of some kind. The basic functionality of the artifact is referred to as the operational principle of the device (Vincenti, 1990). The parts that altogether form the artifact work in combination along a principle to fulfill the purpose of the device. This principle describes how the artifact actually works and thereby defines the artifact.

Arthur (2009) makes a distinction between phenomena and principles. Whereas phenomena are natural effects independent of humans, a principle is the "*idea of use of a phenomenon for some purpose*" (p.49). A principle is yet not sufficient for creating a working artifact. The principle has to be realized into a physical working artifact. This can be done in numerous ways and is not a

straight forward procedure. Vincenti (ibid.) uses the term *configuration* for describing how the operating principle is realized. The configuration contains the arrangements and shapes of how the single parts of the artifact together accomplish the operational principle. As an example; the playground equipment described below would be providing opportunities for children to climb up and down a playground facility. Climbing up and down may be performed by the use of e.g. ladders, nets, ropes, slides or poles which allows for several principles for children to get on and off the facility. The configuration involves in this context how the various parts of the construction are arranged. A proper configuration would have to take into consideration differentiation of challenge for the children as well as security issues with the flow of children up and down the equipment.

The research question in this work is: How does students' creativity relate to fundamental design concepts in projects on Design and Technology in Norwegian schools? The study is conducted as a cross-case analysis of four student projects.

Invention versus designing

What are the characteristics of an invention? No unified satisfying answer can be given though some general aspects seem to be agreed upon. Unlike development and refinement of existing ideas where changes are small, incremental and usually takes place over an extended period of time inventions occur rapidly, ad hoc and unstructured. Mitcham (1994) portrays this twofold nature of designing by using the terms *invention* and *design* respectively; "As opposed to designing, inventing appears as an action that proceeds by nonrational, unconscious, intuitive, or even accidental means. Designing implies intentionally planning" (p.217). A similar view of designing versus inventing is found in Arthur (2009) , who uses the terms *standard engineering* for denoting normal design and *invention* as a representative for radical design.

According to Arthur (2009) there has to be a change in the operating principle if an artifact is to qualify as an invention (p.109). This view is shared by Pye (1964) who claims that "*invention is the process of discovering a principle. Design is the process of applying that principle*" (p.19).

Artifacts and processes introducing a genuine new operational principle will definitely be classified as inventions and a new operational principle will of course imply a new and hitherto unknown configuration. Also known operational principles given a genuine new configuration may count as an invention according to Vincenti (1990). He introduces three types of design; revolutionary design where the operational principle and thus the configuration is completely new, radical design where the configuration is completely new whereas the operational principle may be a modified version of a known principle, often transferred from a different domain, and finally normal design where both the operational principle and the configuration is well known for the designer and the community. In contrast to radical or revolutionary design, normal design is not associated with inventing. Any example of what we today regard as normal design will of course at a point in the past have been considered radical or revolutionary.

To qualify as an invention it seems further to be a general view that the idea has to be realized into a physical artifact. The path from an idea, no matter how detailed planned, to a complete working artifact satisfying the initial purpose is usually not straight forward.

In his thorough book of the genesis and development of technology, Basalla (1988) stresses the significance of play as a source for invention and innovation. Through numerous historical examples he shows how technological dreams, suggestions of impossible machines and popular fantasies has dominated the scope of technological novelties in history. He concludes that there exists no broad theory of technological innovation and that one of the obstacles is that such a theory would have to encompass amongst other factors the irrationality of the playful and fantastic (p.134). Similar views are given by Mitcham (1994) who advocates that from a perspective of emphasizing the historiosocial character of inventing which credits communities of inventors rather than individuals, inventions rarely occur in the chase of solutions to identified problems and needs but rather emerges in the process of playing with ideas (p.217).

Creativity

Though the term creativity is not easily defined or measured it has been given much attention by amongst others psychologists, educators and politicians. Several models describing creativity have been proposed during the last century (Lawson, 1990; Runco & Albert, 1990; Taylor, 1975; Wallas, 1926). Despite different approaches there seem to be broad agreement that creativity involves “*bringing something into being that is original (new, unusual, novel, unexpected) and also valuable (useful, good, adaptive, appropriate)*” (Atkinson, 2000). The latter point is of importance as it demarks creativity from loosely founded ideas that only differ from what already exists without judgment of its value or usefulness.

According to Christiaans and Venselaar (2005), definitions of creativity in the literature is given in terms of personal trait, the process or the product. They argue that the first two of these fail to offer reliable criteria for assessment. Based on the work of Amabile (1983), they conclude that “*..creativity can be seen as a property of products. A product is creative to the extent that observers, familiar with the domain of activity, independently agree it is creative*” (p.220). The results of Cristiaans (1992) confirmed the findings of Amabile (ibid.) that the inter-judge-reliability is high if competent observers independently judge artistic products.

Artifacts produced by the students seem thus most accessible for assessment of the students' creativity. Amabile (1996) offers a definition of creativity that is relevant for technology education and that meets the demand of assessment given by Christiaans and Venselaar's (2005): “*A product or a response will be judged as creative to the extent that (a) it is both a novel and appropriate, useful, correct or valuable response to the task at hand, and (b) the task is heuristic rather than algorithmic*” (p.35). Assuming this as part of the definition of creativity it resembles much of what is regarded as invention discussed above. In light of Vincenti's notion of fundamental design concepts it seems clear that creativity in T&D school projects would involve students either to bring up new operational principles (and thereby new configurations), or they might develop new configurations to already given operational principles. New or novel will in the educational context mean new and yet unknown to the student though it might be well known to professional designers and engineers.

The importance of authenticity is given attention by many authors. Hill (1998) focuses on the importance of open-ended problem solving in real-life contexts when working with T&D in the classroom. She advocates that these contexts are supposed to provide more of the crucial factors that foster creativity; the willingness to take risk, ill-defined problems and the tension between order and disorder. Similar views are found in e.g. Lewis (2005), Cropley and Cropley (2010) and Scott, Leritz and Mumford (2004). In order to stimulate creativity processes Scott et al. (2004) found in their comprehensive study of 70 empirical based studies of creativity training that open-ended, ill-defined problems was superior to expression of unexplored ideas in terms of fostering creativity. They further found that students should be introduced to basic concepts and principles and explore these through extensive training with various discrete cognitive skills and relevant heuristics before they turn to working with exercises appropriate to the domain at hand.

Description of the student projects

The projects were conducted at 4 different schools located in both rural and more urban areas in the northernmost part of Norway. All of the projects were intended to be authentic and open ended, and they were developed in collaboration with the researchers and the teachers in the respective schools.

Project 1 was conducted in grade 8 and the task was to construct and build a model of a drilling rig for oil exploitation. The rig was built partly in Lego with addition of other materials for the chassis of the rig. The Lego Robotics system was used for controlling the operation of the drill. Prior to the project the students were given a short introduction to the essential functions of the Robotics system and basic programming of Lego robots.

Project 2 was conducted at a small rural school including students from grade 3 to 7. The task was to design and build a model of an outdoor fireplace with shelter for thirty people. The shelter

was supposed to have walls, roof and benches nearby a bonfire and was planned to be built in full scale in the vicinity of the school at the end of the school year. The students used the software Google SketchUp for making three-dimensional drawings from which they made templates correct to scale. These were in turn used to cut the parts of the construction in cardboard.

Project 3 was conducted at a rural school in grade 8. The students used SketchUp for designing models of playground equipment for their schoolyard. The design was performed initially by hand-made sketches which was transferred and reworked into detailed 3-D computer drawings. Based on these computer drawings the students made physical models of their artefacts using mainly cardboard as material.

In project 4 the students designed and constructed a model of a house fulfilling their dreams of how they wanted their future house to be. The designing started with hand-made sketches, moving forward to computer based designing using SketchUp before they constructed and painted their house in cardboard according to their final computer drawings.

Research methods

Data presented here is mainly collected by means of videotapes from the classrooms. In each classroom there were 3 cameras filming the activity. Two of the cameras were filming two groups of students respectively while the third was filming the overall situation in the classroom. Also stills were taken through the project process including photos of the products of all groups working in the classrooms. The researchers were present in the classroom engaged in observing the activity and handling the video cameras. As far as possible the researchers avoided influencing the classroom activity letting only the students' regular teachers engage in assisting them. This approach has elements of realist ethnographic nature as described by Creswell (2007). Triangulation between members of the research group has been conducted for selection and interpretation of episodes in the data material. When evaluating the variety of outcomes produced by the students the products of all groups of students in the class were taken into consideration. For analyzing the students' perception of the fundamental design concepts student-student interactions and teacher-student interactions were selected from the material.

Results and discussion

The analysis of the student products along the lines of Amabile (1996) shows that the variety in solutions produced by the student groups differs much from one project to another.

In project 1 (oil rig) the students produced to some extent genuine products; however the basic idea, the operating principle, was common for all groups. The configuration varied to some extent between the groups. Project 2 (outdoor shelter) was the project that showed least variation of the student made products. All of the artifacts were based on the same principle and had configurations that mostly bore a high degree of resemblance to each other. Project 3 (playground equipment) showed products with most variation relative to the other projects. All of the student groups came up with a genuine and unique product. Though the products were founded on basically the same operating principles, they differed significantly in configuration. In project 4 (dream house) the students produced to some extent genuine solutions, however the basic idea for their products were largely the same for most of the groups. The products of this project were evaluated slightly more diverse than those of project 1.

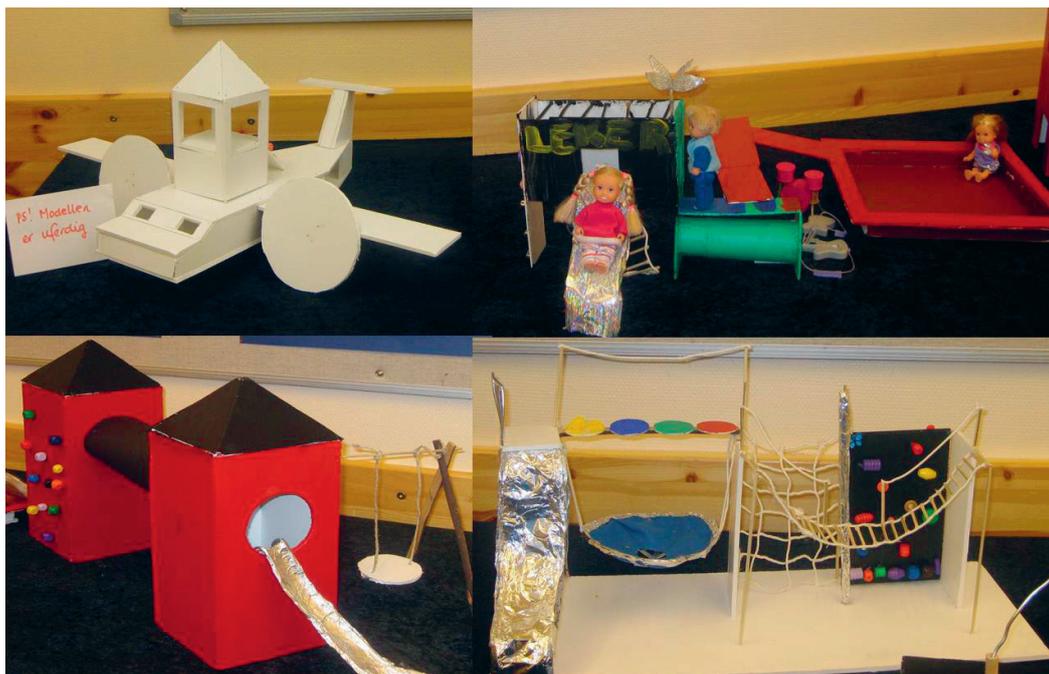
Also the students' perceptions of the fundamental design concepts were found to differ from one project to another. In project 1 (oil rig) the students had severe problems finding an operational principle and were dependent on teacher assistance for adopting a teacher defined principle. One of the groups succeeded in establishing their own configuration whereas the other group was more dependent on teacher guidance in the configuration process. In project 2 (outdoor shelter) the students clearly lacked understanding of the operating principle and thus needed intensive teacher assistance through the stages of the process. Even at the final stages of the process teacher interventions were necessary for the students to have progression in their work in one of the groups.

For this group the notions of normal and radical design is not applicable as they most of the time were carrying out instructions given by the teacher. The other group eventually entered the modus of normal design. In project 3 (playground equipment) the operational principle was apparently understood from the outset whereas the configuration developed through the process. The latter was not a consequence of problems that needed to be solved but was merely an expansion into more complex artifacts. As a consequence the students were in the modus of normal design most of the time where much of their effort was spent on the configuration process. In project 4 (dream house) the operational principle was evident from the start while the configuration had to be developed through the process. The process of developing the configuration was partly influenced by obstacles in the students' design process but also characterized by expansion of already successful ideas.

Images from two of the projects



Picture 1: Artifacts from project 2. This project was found to have least variety between the artifacts.



Picture 2: Artifacts from project 3. This project was found to have greatest variety between the artifacts.

Conclusions and implications

The findings suggest that the projects 2 (outdoor shelter) and 3 (playground equipment) differ most from each other in terms of the variety of the student products. These two projects also differ most in terms of students' perception of the fundamental design concepts. Project 1 (oil rig) and project 4 (dream house) are found between project 2 and 3 both when it comes to variety of products and students' perceptions of the fundamental design concepts. Normal design was found in all of the projects, yet being most pronounced in project 3 (playground equipment) where the students in an early phase of the project entered the modus of normal design. Radical design were most pronounced in project 1 (oil rig) where the students during half of the project struggled with the operational principle and eventually were depended on the teacher to bring them into the modus of normal design.

Based on these results a suggestion would be to spend more time and effort in the initial phases of the project work to assure that the students have a sufficient understanding of the conceptual knowledge and in particular the operating principle of the product they are supposed to construct. True invention in terms of students coming up with their own operational principle seems to be a too demanding task in the general case. It therefore seems necessary to introduce the students to already established operating principles and as a consequence facilitating creativity in exploring configurations. This will emphasize the notion of *design* somewhat at the expense of *invention* using Vincenti's (1990) terms. On the other hand, if students' abilities of *invention* are regarded as a crucial part of their competence gained from working with T&D in school, the tasks must be adjusted to meet this demand. Assuming a sociocultural approach to learning, and with Mitcham's (1994) and Basalla's (1988) view in mind, abilities of *invention* will not benefit from working with predefined problems. Giving students options to play with their own ideas thereby establishing operational principles regardless of the utility of the produced products seem to be more appropriate for stimulating abilities of inventing. In accordance with Scott et al. (2004) these ideas have to be deeply explored and realized into physical artifacts if they are to foster creativity. This requires true open-ended tasks where the teachers' interactions are avoided from being of instructive nature.

References

- Amabile, T. (1996). *Creativity in context: Update to the social psychology of creativity*. Colorado, USA: West View Press.
- Amabile, T. M. (1983). *The Social Psychology of Creativity*. New York: Springer-Verlag.
- Arthur, B. (2009). *The nature of Technology: What it is and how it evolves*. New York: Free Press.
- Atkinson, S. (2000). Does the Need for High Levels of Performance Curtail the Development of Creativity in Design and Technology Project Work? *International Journal of Technology and Design Education*, 10(3), 255-281.
- Basalla, G. (1988). *The Evolution of Technology*. Cambridge: Cambridge University Press.
- Christiaans, H., & Venselaar, K. (2005). Creativity in Design Engineering and the Role of Knowledge: Modelling the Expert. *International Journal of Technology and Design Education*, 15(3), 217-236.
- Christiaans, H. H. C. M. (1992). *Creativity in Design. The Role of Domain Knowledge in Designing*. Utrecht: Lemma B.V.
- Creswell, J. W. (2007). *Qualitative Inquiry and Research Design*. Thousand Oakes, California: Sage Publication Inc.
- Cropley, D., & Cropley, A. (2010). Recognizing and fostering creativity in technological design education. *International Journal of Technology and Design Education*, 20(3), 345-358.
- Hill, A. M. (1998). Problem Solving in Real-Life Contexts: An Alternative for Design in Technology Education. *International Journal of Technology and Design Education*, 8(3), 203-220.
- Lawson, B. (1990). *How designers think*. London.
- Lewis, T. (2005). Creativity- a framework for the design/problem solving discourse in technology education. *Journal of Technology Education*, 17, 35-52.
- Mitcham, C. (1994). *Thinking through technology: The path between engineering and philosophy*. University of Chicago Press.
- Pye, D. (1964). *The Nature of Design*. New York: Reinhold.
- Runco, M., & Albert, R. (1990). *Theories of Creativity*. London: Sage Publications.
- Scott, G., Leritz, L. E., & Mumford, M. D. (2004). The effectiveness of creativity training: A quantitative review. *Creativity Research Journal*, 16, 361-388.
- Taylor, I. (1975). An emerging View of Creative Action. In I. Taylor & J. V. Getzels (Eds.), *Perspectives in Creativity* (pp. 297-325). Aldine, Chicago.
- Vincenti, W. G. (1990). *What engineers know and how they know it: analytical studies from aeronautical history*. Baltimore: Johns Hopkins University Press.
- Wallas, G. (1926). *The art of thought*. New York: Harcourt, Brace and Co.