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Citation: KIPPERMAN, D., 2000. Evaluation-modification loops in the the design process used by students building technological devices. IN: Kimbell, R. (ed.). Design and Technology International Millennium Conference. Wellesbourne : The D&T Association, pp. 100-106

Additional Information:

- This is a conference paper

Metadata Record: [https://dspace.lboro.ac.uk/2134/3393](https://dspace.lboro.ac.uk/2134/3393)

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Evaluation-Modification Loops in the Design Process Used by Students Building Technological Devices
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Abstract
This research is based on observations of and interviews with five seventh grade students during problem solving activities in a technological context. When left to their own devices in an environment rich in three-dimensional materials (Lego components), they follow Evaluation-Modification Loops. The research is based on:

1. observations during class activity over one semester (12 meetings)
2. open interviews with each student during class activities.

The study focused on two issues:

1. identifying the characteristics of the design process of technological devices
2. students’ attitude towards their original design goals during the process of designing technological devices.

An Evaluation-Modification Loops model containing decision making space was developed based on the observations and interviews.

Keywords: cognitive models, design process, technological problem solving, protocol analysis, technological literacy, goal oriented.

Introduction
The study reported here derives from the researcher’s observation that untutored seventh grade students appear to have tacit knowledge of the way to solve a problem in a technological context. Curriculum developers in technology education emphasize the importance of teaching problem solving and suggest following a problem solving model based on linear or cyclical steps (DES, 1987, Hutchinson, J., 1994). However, it is not clear that these models reflect what novice designers actually do. In fact, formal instruction in designing appears to conflict with the tacit strategies students apply in class. In addition, some argue that there is not a single approach for all kinds of problems (De Vriez, 1996, Johnsey, R., 1995).

While there are theories and studies that support the ‘learning by doing’ approach in an unstructured environment, which allows the student to construct his own knowledge (Resnick & Ocko, 1991b), there are studies which clearly indicate that students need to have a well-organized environment in order to feel safe and in control (Kromholtz, 1998). Cognitive psychologists emphasize the intuitive knowledge that students bring to class and the need to take into consideration this kind of knowledge while teaching and developing the curriculum (Driver & Erickson, 1983). On this basis, the goal of this research is to identify the characteristics of the technological problem solving methods students use when building three-dimensional devices (Lego models).

Following this goal, the research questions are:

1. What strategies do students employ when building technological devices in an unstructured environment?
2. To what extent are the students goal-oriented?

This paper begins with a description of the research and a presentation of the findings. A discussion and implications of these findings follows.

Description of the research
Methodology
Five seventh grade students (out of seven in the technology class) participated in the study. This group is one of four groups studying technology for two semesters. The study was conducted during the second semester by which time the students were engaged in building three-dimensional models out of Lego components. Each of the 12 lessons was audio recorded by the researcher. Subjects were encouraged to talk during the activities. In addition, observation notes were taken by the researcher, including interviews during class activities when students were asked to comment on their actions. Figure 1 presents a sample of an interview: (R= Researcher, S=Student)
Figure 1
R: Why do you think it will turn faster?
S: In my opinion, a big wheel turns faster because it has surface. It has a big perimeter, it turns faster.
S: Now I know, it has power (force term)
R: Why does it have power now?
S: This thing gives it power.
R: What is this thing? What gives it power?
S: It’s like the gearbox in my father’s car. Look, it’s slower, it has more power.

The classroom
In the centre of the class there is a large table with Lego components and different instruction manuals which come with the kit. Each of the students decides what he wants to do, if anything. The teaching approach is based on learning by doing in an unstructured environment. The term ‘unstructured environment’ describes a teaching-learning situation that has three main characteristics:

1. the responsibility for learning and activities lies with the students
2. the role of the teacher is to advise when required
3. the students’ activities and their needs dictate the way the lesson evolves.

Figures 2 and 3: Samples of the unstructured learning environment.

Figure 2
S: “Can I start with Lego? I did something last time.”
Goes to the cupboard and takes a car model which he started a week ago.
S: “I intend to keep working on this.”

Figure 3
Sitting and playing with components
S: “I am going to build out of my head. Dov, can you bring me a full kit?”

The teacher’s approach
Two teachers (tutors) are available to answer any questions that the students have. Following are statements often used by the teachers during tutoring:

“I don’t know, what do you think?”
“You’d better try what you just said and later we will talk about it.”
“On the table there are things. Please touch. You are allowed to disassemble, to talk, to ask each other questions and later we will talk.”
“I am against using written instructions. It affects creativity.”

Student attitude toward the technology class
All the students like to participate in the technology class.

Figure 4: Samples of their motivation and enthusiasm.
9.00 The break just started (20-minute break). Two students enter the classroom.
S: “Good, can we start working?”

10.10 (5-minute break)
Teacher: “Guys, this is the time to get some air.”
S: “What a waste of time to go for a break.
R: “You can go for a 5-minute break”
S: “I don’t want 5 minutes, in 5 minutes I can assemble the whole system.”

Preparing the data for analysis
The raw data was systematically aggregated into units which precisely describe the relevant content characteristics. According to Lincoln and Guba (1985) units “are best understood as single pieces of information that stand by themselves, that is, are interpretable in the absence of any additional information” (p. 203).

In this study transcripts were first segmented into speech units and action units. A speech unit includes statements made by students during class. An action unit includes actions taken by the student during class.
This study presents five case studies describing the behavior, actions and statements of five students while they are building technological devices.

Findings
The findings will be presented in three steps according to the analysis procedure of this study. Each step is a refining (magnified) version of the previous step.

Step one - aggregating the units into three main stages
This stage begins when the student enters the class and ends before he connects his device to the power supply. This stage begins with the connection of the device (functional testing) and includes speech units regarding device function and speech units relating to further action. This stage includes action units taken by the student after the evaluation stage. Analyzing the data, we can define the general strategy of the students as Evaluation-Modification Loops strategy.

Figure 5

Step two - looking for characteristics (code set) at each stage
At this point, the speech units and the action units at each stage (construction, evaluation and modification) were grouped to develop code sets (also called criteria in the qualitative research). Glaser and Straus (1967) and Straus (1987) advocated an inductive approach to the development of a code set. Grounded theory (Glaser & Straus, 1967) states that codes should be grounded, that is, derived from the data. Straus (1987) describes the process as “open coding,” defined as “the unrestricted coding of the data aimed at providing concepts that seem to fit the data”. Tesch (1990) refers to “empirical indicators” that is, actions, events and words which could be used to develop codes. As a result of this, open coding codes were derived for each of the stages defined in step one.

Figure 6

Step three: developing a map space of evaluation-modification loops
Design process models found in technology education are often described as graphic linear models containing a number of feedback loops. In this study the design strategy is presented in a graphic map that contains the code set. Such a map makes it possible to identify the behavior patterns of the students, the operation states and the links among them.

Figure 7: Evaluation-modification loops model.

The construction stage includes:

1. the decision making process (where do the ideas come from?)
2. the goal (what type of device to build?)
3. the building process (are they using written instructions?)
4. goal orientation (do they change the goal during the construction stage?)

The evaluation stage includes:
1. connecting the device to interface
2. diagnosis: statements relating to function/dysfunction of the device
3. goal reference: revealing students’ goal orientation space based on concrete action units and speech units during the activity
4. action plan: statements relating to further modifications.

The modification stage includes:
1. building a new model
2. repairing: replacing, adding or substituting components when the device did not function or was functioning in a way that did not meet the student’s expectations
3. troubleshooting: action taken in order to make the device function (testing connectors and subsystems)
4. changing: adding or submitting components to the device in order to improve its performance
5. experiment: testing the device function under various conditions or restrictions.

The research shows that:
1. The students follow a general strategy. Once the construction of the first version of the device was finished, all the students proceed to a manifestly technical step: connecting the device to the interface box in order to see if it actually worked. If it worked, an evaluation vis-à-vis the original goal and modification (usually improvements) track was followed. If it did not work, a fault diagnosis and eventual goal modification (usually repairing or troubleshooting) track was followed. In the case of both a faulty or functioning device, the device was evaluated in reference to the original goal.
2. In both tracks, students entered a series of loops which we called evaluation-modification loops. Those loops include a decision making space which ranged from abandoning the original goal at one end, through reducing, maintaining or expanding the goal on the other end. Accordingly, actions were implemented, and a new loop started (does it work?…) until the student decided that the work was finished.

Discussion
Because of its relatively recent introduction into the school curriculum, technology education has a limited corpus of empirically derived research findings to support the development of curricula. The goals of this research were to:

1. contribute to understanding the process and understanding the skills of student problem solving strategies
2. to develop a method for analyzing untutored student behavior while designing technological devices.

Both the findings and the methodology used to analyse student behaviour have implications for the theory and practice of technology education. In particular, they have implications for the way design is taught to students. These implications will be discussed here in the context of the research question.

The research goals were:

1. to investigate the students’ problem solving strategies
2. to develop a method for analysing untutored students’ behaviour while designing technological devices.

A review of the literature on models of the design process to be used in technology education reveals a gap between the theoretical models and empirical models. While theoretical models deal with what designers ought to do, empirical models describe what designers actually do. This gap is also supported by the classroom observations in this study. Seventh grade students given the opportunity to design technological devices in an unstructured teaching environment do not design in ways described in the theoretical models.

While theoretical models focus on teaching a sequential process based on design stages (DES,1990, Hutchinson, J., 1994) empirical findings do not support them (Hennesy, S. & McCormick, R., 1994). The processes used by the students are more complex than theoretical models and evaluation is an integral part of the process, not just the last stage. These finding match the findings reported by Welch (1996).

The findings in this research support the empirical findings, that is, the process is neither a linear nor a cyclical process. Our own observations instructed us about the particular importance of the student’s own re-formulation of the design stages sequence, and of the task sequence within each stage, guided by their perceived needs at
each step. Highly contextual data as perceived by the student fueled a chain of specific decisions which resulted in nested action – loops involving one or more stages of the design process.

Therefore one particular contribution of this study has been to examine in detail the actual practice of a small sample of untutored designers. Since most of the evaluation (goal reference) is an internal mental process, the evaluation-modification loop model is an analytical tool to reveal the goal oriented space of the students. So, a second contribution of this study has been the methodology for investigation of untutored designer’s behaviour.

Implications for teaching
This study shows that students working in an unstructured environment do not follow all the design stages as presented in the theoretical models. The students decide on constructing a device and immediately start building.

Cognitive psychologists emphasise the intuitive knowledge that students bring to class and the need to take into consideration this kind of knowledge while teaching and developing the curriculum (Driver & Erickson, 1983). Students bring “alternative models” with them to class and use these models according to different contexts (Driver, 1986). This is supported by Barlex (1995) who states that it is “important to … retain the spirit of the experimentation in the design process … and to encourage pupils to find their own methods and frameworks for thinking about problems” (p. 7). Yet at the same time, as Kimbell (1990) has described, students must be provided with a superstructure for designing. They must be able to think and work strategically.

According to this study, the dominant place of evaluation during the design process itself, fosters the approach that defines design as "Interaction between thoughts and actions" (Kelly et al, 1987, p. 14) and later as "Interaction between mind and hand.” (Kimbell et al 1991, p. 20)

It seems that teachers need to adopt teaching strategies that, on the one hand, focus on the nature and the role of evaluation-modification iterations when students are designing and, on the other hand, provide a framework for the students, that is, the ability to see the overall process of design as a goal oriented process.

References

Biographical note
Dov Kipperman designs curricula for science and technology education in the ORT R&D centre in Tel Aviv, ISRAEL. This paper, presented to the DATA conference, is based on a MA thesis submitted to the School of Education at Tel Aviv University.