Development of Curriculum Using Failure Situations in Manufacturing Education

FUJIKAWA Satoshi, ANDO Shigeki* and MIZUKAMI Takemi

Department of Advanced Teacher Professional Development Program, Graduate School of Education, Hokkaido University of Education

*Graduate School of Education, Ashiya University

製作学習における失敗場面を活用したカリキュラムの開発

藤川　　聡・安東　茂樹*・水上　丈実

北海道教育大学大学院教育学研究科高度教職実践（教職大学院）

*芦屋大学大学院教育学研究科

ABSTRACT

The purpose of this study is to develop a curriculum using failure situations to enhance problem solving in junior high school level manufacturing education. To this end, we summarized previous studies involving the effectiveness of failure experiences on causal attribution (Weiner, 1974) and lesson induction (Ichikawa, 1991). We then incorporated learning activities using failure situations and educational support, in order to study failure from the viewpoint of causal attribution and lesson induction. Based on the above approach, we developed a curriculum including performance tasks or prior experiential learnings, and failure situations to enhance students' ability to solve problems, think, judge, and express themselves, in addition to promoting knowledge of the subject material. We believe that this curriculum provides a unique and useful prototype for instruction using failure situations.

1. Introduction

In Japan, technology education in school is considered to play a role in character formation as well as academic achievement through manufacturing (Ando et al., 2016). However, JSTE (2014) reported that the amount of time allocated to technology education is extremely small when compared with other countries (e.g., 12 years in the United States, Canada, and the UK, 10 years in France, and 3 years in Japan). Furthermore, Nakazono (2012) indicated that the number of hours allocated to junior high schools per year is decreasing annually (e.g., 315 hours in 1958; 87.5 hours in 2008). As a result, projects are planned for production learning that can be easily completed in a short amount of time, leaving little room for students to experience and learn from failures. We believe that experiencing and reflecting on failure experience is necessary for character formation as well as technical ability.

In this paper, we demonstrate a curriculum using failure situations in manufacturing education. Through the development of such a curriculum, we intend to enhance students' ability to solve problems, think, judge, and express themselves, over and above the mere transference of information from student to teacher. Specifically, we looked at manufacturing education at the junior high school level. We incorporated effective learning activities using intentional failure situations and prepared educational support for failure, in response to the theories of causal attribution and lesson induction

2. From View Point of Causal Attribution

In this chapter, we summarized the literature on causal attribution. Weiner (1974) showed that people who attribute the root cause of failures to internal and uncontrollable factors such as lack of ability tend to have low motivation, while those who attribute the factors such as lack of effort tend to have high root cause of failure to internal and controllable motivation. Many subsequent studies on motivation have built on the theories of Weiner. However, most of these studies were limited to lecture-based subjects such as mathematics and science. We could not find any studies applying the causal attribution theory to production learning in technology education.

Next, we summarized previous literature on failure and motivation in production learning in technology education. Existing studies have considered various factors such as age, grade, and sex as they pertain to differences in motivation (e.g. Doi, 1998), and analysis of "failure anxiety" (e.g. Yamamoto et al., 2005). Moriyama et al. (2005) studied degrees of motivation after failure compared with motivation levels before production with respect to technology education. However, we could not find studies on how failure experiences in production learning affect learning motivation.

To cover this deficit, we examined the relationship between beliefs about failure and causal attribution in the production learning of junior high school students (Fujikawa et al., 2016). In doing so, we examined the correlation between Ikenda et al.'s (2012) "scale to measure beliefs about failure" and the "questionnaire to investigate the causal attribution of failure in the learning of wood processing" in junior high school students who went through a production learning program in wood products. In five failure experiences out of ten, a significant correlation was found between "ability attribution" and "negative beliefs about failure" (shown in table 1). In other words, students who consider lack of ability as the root cause of their failure tend to have lower motivation to achieve their goals after they have failed.

Based on the above, we propose that teachers require students to examine their failure before advising them on how to obtain success. In addition, teachers must help students grasp that the cause of their failure is the controllable lack of training, not the uncontrollable lack of ability.

3. From the Viewpoint of Lesson Induction

In this chapter, we confirmed Ichikawa's lesson induction (1991a, 1991b). In examining "how to use failure as the basis of learning," emphasis was placed on the question "Why could the student not perform the task?" Such reflections have been shown to encourage meta-cognitive abilities, especially the "ability to grasp the cognitive state of self" and the "ability to control the learning state of self."

However, many studies related to lesson induction focused on mathematics and science, and no findings related to technology education could be obtained.

Next, we outlined previous studies on failure experiences and educational strategies in technology education. There were many studies on teaching materials, tools, and methods to avoid failure. There were also studies that brought attention to the usefulness of failure and adopted it in the development of learning materials. However, no studies reported that failure experiences in production learning influence subsequent academic ability.

Subsequently, we investigated how failure experiences in wood processing learning relate to knowledge consolidation (Fujikawa et al, 2014). In the present study, based on the findings of Hatamura's (2005) failure analysis and Ichikawa's (1991a, 1991b) theory of lesson induction, we classified failure experiences into two groups: when the person found and considered the cause of failure (CA-type failure experiences) or when the person could not find or did not consider the cause (NC-type failure experiences) and examined the differences in knowledge consolidation between the two types. Specifically, we conducted production learning for first-year junior high school students and subsequently carried out a written test of the students' skill knowledge and extracted the number of CA-type and NC-type experiences of each student from the questionnaire survey. Furthermore, we examined the correlation between "number of failure experiences" (both types) and "skill knowledge score" (shown in table 2).

Table 1 Correlation Between Failure Value and Causal Attribution (Described Based on Fujikawa 2016)

Failure experiences	Factor of Failure Value Scale	C.A. (internal)		C.A. (external)		
		Effort	Ability	Task	Luck	Teacher
Mistake in measuring length by making line	F1: Negative affective valence	.11	.28**	.09	.03	.05
	F2: Learning orientation	.07	-.19**	.07	.16*	-.06
	F3: Need to avoid	.04	.16*	.09	.14	.06
	F4: Perceived probability of occurrence	.00	.06	.06	-.15*	.04
Wood got split with saw	F1: Negative affective valence	.11	.35**	.13	-.14	.00
	F2: Learning orientation	-.05	-.26**	-.01	-.02	-.07
	F3: Need to avoid	.06	.24**	.11	.00	.03
	F4: Perceived probability of occurrence	-.11	.01	.12	-.05	-.09
Not straight line in scraping with planing	F1: Negative affective valence	.12	.23**	.03	-.06	-.08
	F2: Learning orientation	.09	-.18**	.03	-.08	-.14*
	F3: Need to avoid	-.03	.17**	.08	.03	-.03
	F4: Perceived probability of occurrence	.00	.00	.06	.00	.03
Wood got split with planing	F1: Negative affective valence	.08	.26**	.16*	.03	-.08
	F2: Learning orientation	.11	-.09	.05	-.06	-.18**
	F3: Need to avoid	.00	.23**	.19**	.07	.05
	F4: Perceived probability of occurrence	.03	.06	.02	.03	-.15*
Traces of hammer on the wood with nailing	F1: Negative affective valence	.27**	.34**	.31**	.05	-.04
	F2: Learning orientation	.04	-.18	-.04	-.16	-.13
	F3: Need to avoid	.10	.24*	.25*	.03	-.09
	F4: Perceived probability of occurrence	.08	.04	.17	.10	.04

The results of the investigation revealed a significant correlation between the number of CA-type failure experiences and skill knowledge score (R = .312, $p < .01$). However, there was no significant correlation between the number of NC-type failure experiences and skill knowledge score ($r = -0.147$, $p < .05$). CA-type failure experiences appear to promote knowledge consolidation.

The efficacy of educational intervention based on lesson induction was examined in our previous study (Fujikawa et al., 2015), as below. In order to verify the effects of learning that incorporates CA-type failure experiences, we conducted experiments comparing conventional teaching methods with teaching methods that incorporate CA-type failure experiences for junior high students. The experimental methods were as follows: prior to production learning, we conducted a comparative experiment in which students learning to saw were divided into two groups: one received conventional teaching methods (control group) and another experienced intentionally implemented CA-type failure experiences (experiment group). Following production learning, we examined the differences between the mean scores of the written test on knowledge of sawing (6 points total) and the practical skills test for sawing (6 points total). The written test scores of the experiment group were significantly higher than those of the control group (4.14 and 4.78, respectively, $t = 2.42$, $p < 0.05$, shown in table 3).

Based on the results of the prior study shown in this chapter, it was suggested that preceding learning that incorporates CA-type failure experiences may significantly improve the establishment of skill knowledge. Production learning, which entails the physical creation of a product, contains activities that utilize not only the brain but also the body. Therefore, we consider that failure experiences in production learning can be more readily committed to memory and applied to future lessons.

4. Curriculum Development Using Failure Situations

Based on the previous study shown in chapters 2 and 3, we developed a curriculum using failure situations in manufacturing education, intending to enhance students' ability to problem solving, think, judge, and express themselves, as well as to learn the skills being taught.

Specifically, we applied intentional failure situations to the woodworking education experience of junior high school students. We incorporated effective learning activities such as performance tasks or prior experiential learnings, using failure situations from the viewpoint of lesson induction, and prepared educational support for failure from the viewpoint of causal attribution. The curriculum is shown in table 4.

Table 2 Correlation between Failure Experience and Skill Knowledge (Fujikawa et al., 2014)

	CA-type failure experience	NC-type failure experience
skill knowledge	0.312**	−0.147*

N = 241, $^{**}p < .01$ $^{*}p < .05$

Table 3 Results of the t-test on Sawing Knowledge (Fujikawa et al., 2015)

Item		Control group ($N = 58$)	Experiment group ($N = 59$)	t-value
Sawing knowledge	*Mean*	4.14	4.78	2.42*
	SD	1.63	1.22	

Independent t-test (two-side), $^{**}p < .01$ $^{*}p < .05$

Table 4 Curriculum Using Failure Situations in Manufacturing Education

Headings	Items	Learning contents	Instructions using failure situation
#1. Technology used in our lives and industries	A. To deliberate the roles of technology in improving our lives and in succession and development of industries	A-1: Change of life and the industry that technology development brought	
		A-2: Kind of our various familiar technologies	
	B. To deliberate the relationship between technological improvements and the environment	B-1: Technology and environment	The teacher makes the students realize the fact that development of technology enabled our rich lifestyle, but caused environmental disruption, and make the students understand the positive and negative effects that technology has. (Debate, Discussion)
		B-2: Technical progress and construction of the sustainable society	
#2. Materials and their processing methods	C. To understand the characteristics of each material and their use	C-1: Characteristic of wood	
		C-2: Characteristic of metal, characteristic of plastic	
	D. To understand processing methods appropriate for each material and be able to use tools and equipments safely	D-1: Processing method suitable for materials (wood)	
		D-2: How to use tool and equipments	
	E. To deliberate the proper evaluation and the use of technology of materials and their processing	E-1: Present situation and future direction in technology education	
#3. Design and production of objects applying technology of materials and their processing	F. To deliberate the functions and structures appropriate for their purposes and usage requirements	F-1: To consider about the work that we want to produce through the observation of familiar products	
		F-2: Strong structure	
	G. To understand the methods for communicating ideas and be able to make a production drawing.	G-1: Graphics	
		G-2: Design of the work	The teacher shows a product with bad design and make them examine how to improve the design. (Performance task)
		G-3: To draw a conception picture of the work	
	H. To be able to fabricate parts, assemble them and finish products.	H-1: How to use tool	
		H-2: Prior experiential learning incorporating CA-type failure experiences	The teacher makes the students experience themselves what kind of failure resulted from sawing in the incorrect manner, and to make the students examine the causes of failure. (Prior experiential learning)
		H-3: Marking off	
		H-4: Cutting with a saw	The teacher makes the students examine their failure, and to makes the students grasp that cause of their failure is lack of training but not their uncontrollable ability. (Support under causal attribution)
		H-5: Parts processing #1 (sharpening with a plane)	
		H-6: Parts processing #2 (drilling with gimlet for nail)	
		H-7: Assembling	
		H-8: Finishing (sandpaper and painting)	

In the curriculum shown in table 4, the section "G-2: Design of work" indicates that teachers are to explain the task and usage requirements, and then the students design their work. We adopted performance tasks using failure situations as follows: the teacher shows a failed product with a bad design and asks the students how to improve the design. The contents of this activity are shown in table 5. In G-2-1 of table 5, the teacher explains the functions and structures of the product for purposes and usage requirements based on a textbook (Kato et al., 2005). In G-2-2 of table 5, students observe a product with a bad design and consider how to improve the design through collaborative learning. Thereafter,

Table 5 Performance task

Period	Contents
G-2-1	・To understand the functions and structures for users purposes and usage requirements.
G-2-2	・To observe a product with bad design and examine how to improve the design. ・To observe some products with good design and examine what sort of devises is conducted.
G-2-3	・To design their work.

Table 6 Prior Experiential Learning

Period	Contents
H-2-1	・To understand the correct method of sawing.
H-2-2	・To experience what kind of failure resulted from sawing in the incorrect manner, and think about the causes of failure. ・To understand the causes of failure.
H-2-3	・To practice sawing utilizing the correct method.

students observe some products with good designs and consider what sort of devices are used in the product through collaborative learning. In G-2-3 of table 5, students design their own work while referring to G-2-1 and G-2-2. This activity is expected to enhance student ability to problem solve, and to think, judge, and express themselves through problem solving.

In "H-2: Prior experiential learning incorporating CA-type failure experiences" of table 4, the teacher allows the students to experience for themselves the failure that results from sawing in the incorrect manner, and asks the students to examine the causes of failure. This activity is constructed based on our prior study (Fujikawa et al., 2015). The contents of this activity are shown in table 6. In H-2-1 of table 6, the teacher instructs the correct method of sawing from a textbook (Kato et al., 2005). In H-2-2 of table 6, the teacher has the students carry out sawing in an "incorrect manner," contrary to the instructions in the textbook so that they experience failure. Students are then asked to think and write about the causes of failure. In this way, students are intentionally made to experience CA-type failure. In H-2-3 of table 6, students practice sawing utilizing the correct method described in the textbook. This activity is expected to improve the establishment of skill knowledge through CA-type failure experiences based on our prior study (Fujikawa et al., 2015) as well as the theory of lesson induction. In the period from "H-4: Cutting with a saw" to "H-8: Finishing" in table 4, the teacher refrains from advising the students for success, making them examine their failure first and helping them see that the cause of their failure is the controllable lack of training, not the uncontrollable lack of ability. This learning support is expected to prevent decreased motivation to experience failure as part of the learning process under the theory of causal attribution. In addition, it is inferred that this learning support replaces the students' NC-type failure experiences with CA-type failure experiences. Based on the theory of Fujikawa et al. (2014), this learning support is expected to improve the establishment of skill knowledge.

Thus, this curriculum adopted an active learning situation involving failure based on lesson induction such as performance tasks or prior experiential learnings. In addition, this curriculum incorporates learning support for failure under the theory of causal attribution. Therefore, this curriculum is expected to enhance students' ability to problem solve and think, judge, and express themselves, and finally to improve their motivation to use failure in achieving their goals.

5. Conclusion

In this paper, we developed a curriculum using failure situations in manufacturing education. In designing the curriculum, we intended to enhance students' ability to problem solve and to think, judge, and express themselves, as well as to establish skill knowledge in junior high school level manufacturing education. Specifically, we incorporated effective learning activities using intentional failure situations, and prepared educational support for failure, from the viewpoint of causal attribution and lesson induction. We contend that this curriculum offers a unique and useful example of instruction using failure situations.

Students experience various failures in learning activities. Teachers are required to appropriately support the apparent failures of students, which will lead to a certain level of academic ability and character development. Student failure in learning activities is an important challenge for teachers. In such situations, the maxim "failure is the mother of success" is often used to encourage students to not lose their motivation. However, instruction using failure situations has not been suggested concretely in designing education curricula. We believe this study provides a unique and useful example for curriculum development in general.

This study is limited in that it is based on prior theory—causal attribution and lesson induction—and needs to be verified in an empirical setting. This verification is our next step.

Acknowledgements

The authors would like to thank Dr. Takanori Maesako of Osaka University for his great instruction in the human sciences. Thanks also to Dr. Fumitaro Sekine (honorary professor of Kyoto University of Education) for his excellent instruction on material processing in technology education. Finally, the authors would like to thank Editage (www.editage.jp) for English language editing. This work was supported by JSPS KAKENHI (17K04731)

References

Ando, S., Harada, S, Fujikawa, S. (2016). Why is technology education necessary? with a focus on manufacturing education in junior high schools in Japan, Proceedings of ICAEME 2016, 103-107.

Doi, K. (1998). Self-consciousness related to manual dexterity or clumsiness among primary and secondary school students, *Journal of the Japan Society of Technology Education, 40*(1), 23-31.

Fujikawa, S. & Sekine, F. (2014). Motivation and acquisition of knowledge: The effectiveness and relation of failure experiences in the area of woodworking in technology education, *Journal of the Japan Society of Technology Education, 56*(1), 51-58.

Fujikawa, S., Sekine, F., & Maesako, M. (2015). Benefits of prior learning in woodworking education by incorporating failure experiences, 5th Pacific Rim Conference on Education Proceedings, 97-109.

Fujikawa, S. & Maesako, T. (2016). Relationship between beliefs about failure and causal attribution in production learning of junior high school students, *International Journal of Innovations in Engineering and Technology, 7*(4), 67-74.

Hatamura, Y. (2005). Encouragement for study of sailure (pp.65-90), Kodansha LTD.

Ichikawa, S. (1991a). Case study in cognitive counsel, lesson induction in problem-based learning (Edit: Hakoda, Y., Frontia in Cognitive Science #1, pp.145-152), SAIENSU-SHA Co., Ltd,

Ichikawa, S. (1991b). Correlation with basic psychological study (Edit: Hakoda, Y., Frontia in Cognitive Science #1, pp.152-160), SAIENSU-SHA

Co., Ltd.

Ikeda H. & Misawa, R. (2012). Conceptualization and measurement of beliefs about failure. *The Japanese Journal of Educational Psychology, 60*(4), 367-379.

JSTE (2014). How is technology education in the world currently being enforced? Retrieved November 15, 2018, http://www.jste.jp/main/data/sheet4.pdf.

Kato, K. et al. (2005), Technology and Home Economic: Technology (Textbook for junior high school approved by MEXT), THOKYO SYOSEKI CO., LTD.

Moriyama. J., Watanabe, K., & Miyagawa, Y. (2005). Student reactions to misjudgments during technology education, *Journal of the Japan Society of Technology Education, 51*(4), 255-262.

Nakazono, M. (2012). The Prospect of future education through the past educational practices of the technical and homemaking course. *Research Report of Daiichi Institute of Technology*, 24. 63-74.

Weiner, B. (1974). Achievement motivation and attribution theory. Morristown, N. J.: General Learning Press.

Yamamoto, T., Moriyama, & J., Matuura, M. (2005). The structure of students' reflections in skill learning processes in metalwork class in technology education at the junior high school level, *Journal of Japanese Curriculum Research and Development, 28*(2), 71-80.

Add: This work was presented at the 4th International Conference on Applied Electrical and Mechanical Engineering 2017 (ICAEME 2017), Nongkhai, Thailand.

（藤川　　聡　旭川校教授）
（安東　茂樹　芦屋大学教授）
（水上　丈実　旭川校教授）