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Improving Motivation Control in Personal Software Process Education Course with a Qualitative Approach

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Abstract

One of the problems of our PSP (Personal Software Process) training course class is a low completion rate. One of the trials to resolve the situation is formalizing the motivation process of the PSP course trainees by using state transition modelling with the state, values of the factors regarding the trainee's motivation and a set of stimuli from the course instructors and environment. Conceptually, instructors can make effective scenarios for the trainees and develop an effective learning environment with the assumption on the state and corresponding state transition function of the trainees. However, it is difficult to improve as well as design and evaluate such scenarios and environment factors based on the actual motivation states inside trainees. We use a qualitative approach, GTA (Grounded Theory Approach) with a systems-engineering modeling method to improve as well design and evaluate scenarios and environment factors.

Keywords: software development process, instructional design, qualitative approach, systems engineering

1 Introduction

Kyushu Institute of Technology (Kyutech) offers a training course of PSP (Personal Software Process) followed by a TSPi (introductory Team Software Process) course [1][2][3] in addition to PBL (Project Based Learning) as a part of practical engineering education. One of the problems of the class is a low completion rate and professors have been trying to resolve the situation. In general, when an individual or organization tries to introduce a new technology or method, it is necessary to appropriately motivate the individual or organization. In introducing a process establishing and improving method such as PSP through the corresponding training course, we also need consider this issue.

Figure 1 shows our approach for this issue. Our goal is to improve a low completion rate of the PSP course and we focus on the motivation of trainees to address this issue ((1) in

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Figure 1). We formalize the motivation process of the PSP course trainees by using state transition modelling with the state, values of the factors regarding the trainee's motivation ((2) in Figure 1). We use a systems engineering and resilience engineering method, Functional Resonance Analysis Method, FRAM[7] to model scenarios in the training course ((3) in Figure 1). We use a qualitative approach, Grounded Theory Approach, GTA[8][9], to analyze theories in the course to evaluate and validate our scenarios ((4) in Figure 1).

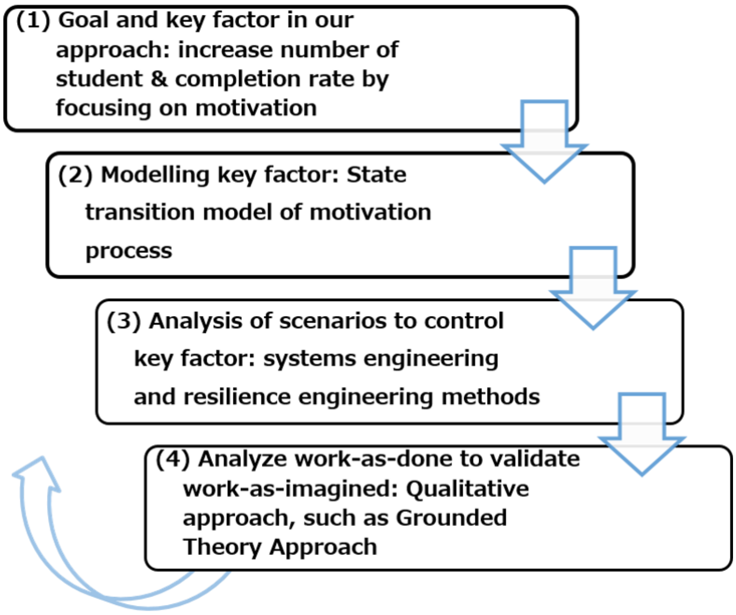

Figure 1: Our approach to PSP training course improvement

The model of state transition in a motivation process [4] based on the Organizational Expectancy Model [5] is useful for the analysis of a process in introducing and establishing a new technology or method. The Organizational Expectancy Model models interactions between the target process and its monitoring and controlling process from a viewpoint of motivation process. This Organizational Expectancy Model is also useful for software process education in a university setting even though the parameters of the factors in the model, such as the content of rewards, are different between working environment and educational environment.

There have been proposed two state transition models based on the Organizational Expectancy Model for managing and improving the PSP training course. The first one is the Baseline-State Transition Model (Baseline-STM)[4]. The second one, a practical state transition model (Practical-STM) of a motivation process in the PSP course is defined in order to more precisely manage the course compared to the Baseline-STM according to the actual experiences of instructors [6]. The Practical-STM is intended to extract the detailed features or characteristics of trainees related to the motivation for PSP. It is useful for instructors to presume states and state transition functions of the trainee during the course. This model enables us to formally describe a scenario, a state transition path of the motivation process, on which a trainee falls into a specific motivation state. As the next step, we need a method to develop effective scenarios based on the Practical-STM applicable to real situations during the PSP training course.

Theoretically, instructors can develop effective actions for the trainees based on the assumption on the state and the corresponding state transition function of the trainees. However, it is difficult to analyze and evaluate the instructor scenarios, series of instructions during the PSP course, by considering the trainee's real motivation invisible from instructors. We use systems engineering and resilience engineering methods such as FRAM in our approach to model scenarios in the training course. We also use a qualitative approach, Grounded Theory Approach, GTA, to analyze theories in the course and evaluate our scenarios.

In the rest of the paper, section 2 describes the structure and state transition model of a motivation process based on the Organizational Expectancy Model, and introduces the Practical-STM in the PSP course. Section 3 introduces FRAM and explains improvement with FRAM. Section 4 introduces GTA and evaluation of improvement using GTA. Section 5 makes concluding remarks.

2 State Transition Model of Motivation Process

As explained above, in (2) of our improvement approach, we focus on the motivation process of trainees in our PSP training course. We formalize the motivation process of the PSP course trainees by using state transition modelling with the state, values of the factors regarding the trainee's motivation.

2.1 Motivation process and its structure

Our formalization is based on the Organizational Expectancy Model that incorporates factors related to the environment or organization into the Expectancy Model [10]. Figure 2 illustrates the motivation process model based on the Organizational Expectancy Model. It represents the relationship between a personal motivation process embedded in a context of a project to introduce new technologies or methods, and a monitoring and the controlling process in the environment or organization to which the project belongs [4]. In Figure 2, *Bep* is the person's belief concerning the probability (i.e., subjective probability from 0 to 1) that the performance *P* at that level will be achieved if an effort *E* performing at that level is made. Bpo_i is a person's subjective probability from 0 to 1 that *P* at the intended level will lead to an outcome O_i ($i \geq 1$), where *i* is an index to an individual outcome. V_i is a valence from -1 (very undesirable) to +1 (very desirable) that represents the degree of personal emotion or preference for O_i that *P* leads to. $Bpo_i * V_i$ is summed up as there are more than one O_is in general. $Bep*\Sigma_i (Bpo_i*V_i)$ denotes that the motivation *M* is high if the possibility that *E* leads to *P* at that level is high ($Bep \gg 0$), the possibility that *P* leads to O_i is high ($Bpoi \gg 0$), and O_i is desirable ($V_i \gg 0$).

E is determined by *M*, while $P = E*C*R$, where *C* denotes a person's prerequisite ability and *R* denotes a person's role perception. The role perception *R* is a person's perception in which the effort *E* leads to performance *P*. *P* leads to outcomes O_i, which are either or both of intrinsic rewards *Rint*, such as a sense of job accomplishment, and extrinsic rewards *Rext*, such as a pay raise or promotion. The job satisfaction *J* is given as $J = Rint * Rext * Requ$, where *Requ* denotes a person's perception of equitable reward. The example effects of *J* are absenteeism, grievances, and organizational identification. Arrows *X1*, *X2*, and *X3* denote that personal experiences in the processes of $E \rightarrow P$, $P \rightarrow O_i$ will affect *Bep*, Bpo_i and O_i, and V_i, respectively.

Environmental and organizational factors of the monitoring and controlling process represent the external factors that affect the personal motivation process. For example, operations, such as giving an instruction and an advice, by the monitoring and controlling process affect *R*. Operations issuing written appointments, such as those relating to a pay raise or promotion, affect *Rint* and *Rext*. Operations announcing a compensation plan or personnel assessment system affect *Requ*. Because *R* and *Requ* are directly affected by environmental and organizational factors, the arrows on the both sides from the monitoring and controlling process are connected to the corresponding factors. On the other hand, the arrow from the monitoring and controlling process is connected to the arrows from *P* to *Rint* and *Rext*. This is because the relationship between *P* and rewards is reinforced by the environmental and organizational factors.

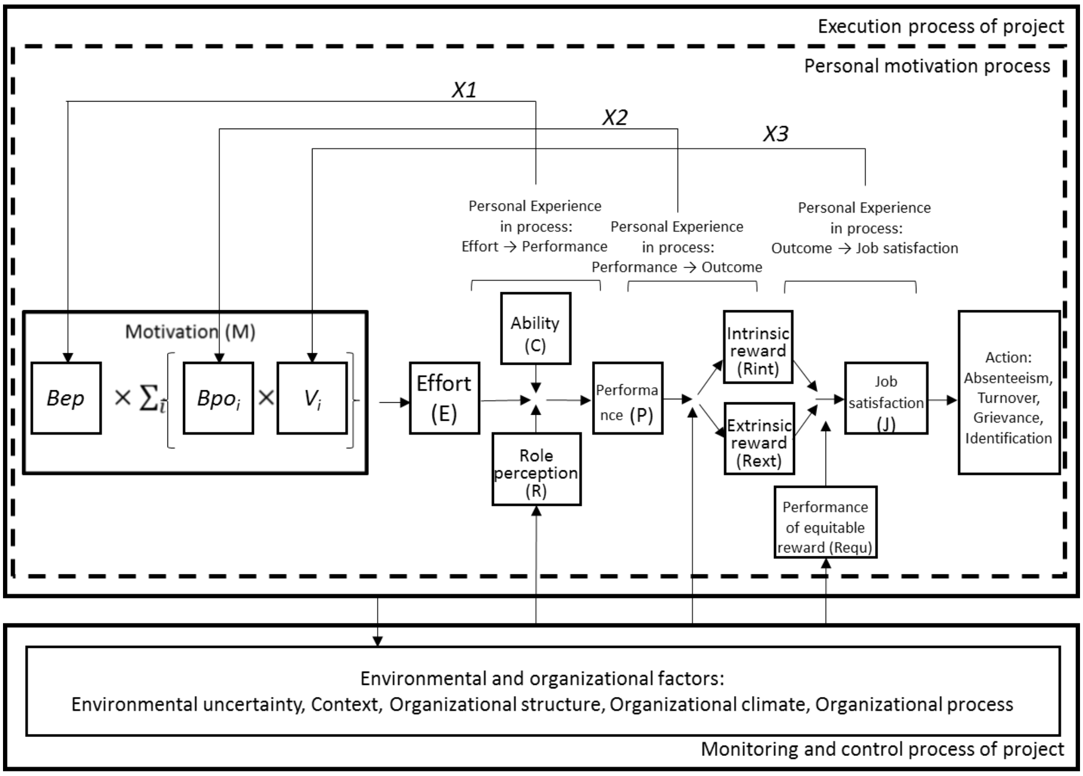

Figure 2: The structure of motivation process based on the Organizational Expectancy Model.

2.2 Factors in the motivation process

The Practical-STM treats an individual trainee of the PSP course as a state machine, and formalizes a motivation process of a trainee using a set of states represented by factors regarding motivation and a set of operations from course instructors.

Table 1 shows factors and state values of the Practical-STM. Each factor has discrete values, such as {VeryHigh, High, Low, Unknown} for the effort E. While there exist several versions of SEI-certified PSP training, we assume the PSP for Engineers, consisting of two sub-courses, PSP-Planning and PSP-Quality. Each sub-course has four days each of which is a pair of a half-day lecture and the corresponding assignment and the fifth day of the postmortem report. According to this course structure, 10 performance factors are used for eight assignments, intermediate report, and final report. For the role perception *R*, 87 factors are used according to the contents of the PSP for Engineers [6].

Theoretically, the instructors can decide effective actions for the trainees based on the assumption of the state and the corresponding state transition function of the trainees. However, it is not easy to develop and analyze the instructor scenarios, series of instructions during the PSP course, by just using the motivation state of trainee students. While each factor in the motivation process model has a small number of state values, such as {VeryHigh, High, Low, Unknown} for effort *E*, the wholistic state space is very large as there exist multiple factors in the motivation process model. Thus, we use a top-down modeling approach with abstraction rather than a bottom-up one with direct use of factors in developing and analyzing instruction scenarios for the PSP training course while considering the motivation state of the trainees.

As a method to model scenarios, we use FRAM, originally proposed for "Safety-II" to model and analyze instructor scenarios for the process training course. We also use GTA to analyze phenomena and theories during the PSP training course to validate our assumptions and scenarios based on them.

Table 1: Factors and their values in the Practical-STM

Factor	**State value set**
Bep	{VeryHigh, High, Low, Unknown}
Bpo	{High, Low, Unknown}
V	{High, Low, Unknown}
Effort *E*	{VeryHigh, High, Low, Unknown}
Ability *C*	{VeryHigh, High, Low, Unknown}
Role Perception *Ri* (i=1..87)	{Perceived, NotPerceived, Unknown}
Performance *Pj* (j=1..10)	{Accomplished, NotAccomplished}
Assignment A*j* (j=1..10)	{NotGiven,Given,PlanningCompleted,Completed}
Intrinsic Reward	{Given, NotGiven}
Extrinsic Reward	{Given, NotGiven}
Job Satisfaction	{HighLevel, LowLevel}

3 Modelling with FRAM

We use a systems engineering and resilience engineering method, Functional Resonance Analysis Method, FRAM to model scenarios in the training course ((3 in Figure 1. In this section, we briefly introduce FRAM and our approach with FRAM.

3.1 Requirements in improvement

In improving instruction scenarios from instructor's point of view, we considered the following issues and hypothetical corresponding intervention actions based on the Practical-STM shown in Figure 2.

1. A trainee quits the course before satisfying the PSP completion criteria originally set by SEI, completing all exercises, the intermediate report, and the final report.
   - Instructors and lecturers from industry explain the life-long importance of the PSP completion through activities like special workshop and lecture.
2. A trainee quits the course before satisfying the course credit criteria set by Kyutech, completing two-thirds of exercises.
   - Instructors explain the requirements for the credit in a comprehensive way so that trainees can have perspective for the credit.
3. A trainee repeats the same mistake without improving his/her personal process.
   - Instructors assist the analysis of the reason why the trainee cannot achieve improvement, and repeatedly give advice for the corresponding issues.
4. A trainee cannot generalize lessons learned.
   - Instructors repeatedly give advice for the corresponding issues without directly giving the answer.
5. A trainee cannot complete his/her exercise within the scheduled time frame.
   - Instructors set appropriate small-step milestones to check the progress of trainees and make some mitigation actions like rescheduling of class or assignment.
6. A trainee cannot make enough analysis in proposing his/her process improvement plan.
   - Instructors advise to facilitate the awareness of trainees.
7. A trainee cannot realize his/her process improvement due to his/her low engineering skill.
   - Instructors give advices from a viewpoint of software engineering

Although we use the Practical-STM, a state transition model, trainees are not computing machines. Our intervention actions sometime do work and sometime do not work. In order to model such situation, we use the FRAM whose basic principles include the principle of equivalence of successes and failures as explained below.

3.2 Functional Resonance Analysis Method, FRAM

The FRAM is proposed to analyze how something has been done, how something is done, or how something could be done in order to produce a representation of the thing in a reliable and systematic manner, using a well-defined format. The resulting representation is effectively a model of the activity capturing the essential features of how something is done. In the case of the FRAM, the essential features are the functions that are necessary and sufficient to account for the activity together with the way in which the functions are coupled or mutually dependent.

Although the FRAM was developed in the context of the common understanding of safety, it is not just a safety or accident analysis method. The FRAM can be used for task analysis, system design, etc. We refer to safety engineering that produced the FRAM as Resilience Engineering. In Resilience Engineering we believe system safety is achieved through flexibility to environmental fluctuations and unintentional input [7][11]. At the same time, such flexibility may in turn create unintended behaviors. The FRAM is a method without defining any failure event of the system as opposed to conventional safety analysis which define the event that the system fails. The FRAM is based on four principles or assumptions about how things happen. The four principles are:

1. The principle of equivalence (of successes and failures): this is the assumption that different kinds of consequences do not necessarily require different kinds of explanations causes, but that the same explanation can be used in most – if not all – cases.
2. The principle of approximate adjustments: this is the assumption that people continuously adjust what they do so that the actions match the conditions.
3. The principle of emergence: this is the acknowledgement that not all results can be explained as having a specific, identifiable cause.
4. The principle of resonance: in cases where it is neither possible – nor reasonable – to base explanations on the cause-effect principle (causality), functional resonance can be used instead to describe and explain non-linear interactions and outcomes.

A function in the FRAM is modelled with the six aspects shown in Table 2. In the graphical notation, a function is depicted as a hexagon as shown in Figure 3.

Table 2 : Six aspects of FRAM function

	Aspect	
I	Input	That which activates the function and/or is used or transformed to produce the output. Constitutes the link to upstream functions.
P	Precondition	System conditions that must be fulfilled before a function can be carried out.
R	Resource	That which is needed or consumed by the function when it is active (matter, energy, competence, software, manpower).
T	Time	Temporal aspects that affect how the function is carried out (constraint, resource).
C	Control	That which supervises or regulates the function, e.g. plans, procedures, guidelines or other functions.
O	Output	That which is the result of the function. Constitutes the links to downstream functions.

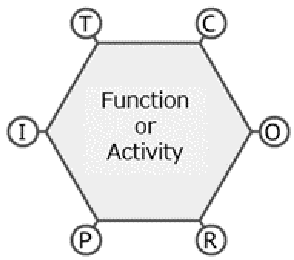

Figure 3 : Graphical notation of a function in the FRAM

Modeling in the FRAM begins with a detailed definition of each function, and as a result of analysis, the entire network is modeled, and the success factor of the system is derived. The FRAM is an induction method and is directed to "integration based on success", while conventional methods are deductive and "decomposition based on failure" is performed.

3.3 Modeling in the large

We explains modeling in improving the PSP course in the consideration of the motivation of our trainees. Figure 4 is a holistic FRAM model of PSP for Engineer I, which consists of the five lectures, four assignments and an interim reports. In the model, a function named “Trainer i”, i=1,..5 is a function corresponding to the instructor role for the i-th lecture and assignment. Trainer functions like this are aligned in a horizontal row with the same color, blue for example. PSP course materials are provided from CMU/SEI, Software Engineering Institute of Carnegie Mellon University. Instructors guide the trainees by using the materials containing a series of assignments and reports. In the PSP course, trainees master a series of gradually advanced processes. A function named “Trainee's Decision i”, i=1,..5 is a function corresponding to the trainee’s motivation process for the assignment i. A function named “Assignment i”, i=1,..5 is a function corresponding to the trainee’s work for the assignment i. Trainee’s Decision functions and Assignment functions are also aligned in a horizontal row with the same color, respectively red and green, for example.

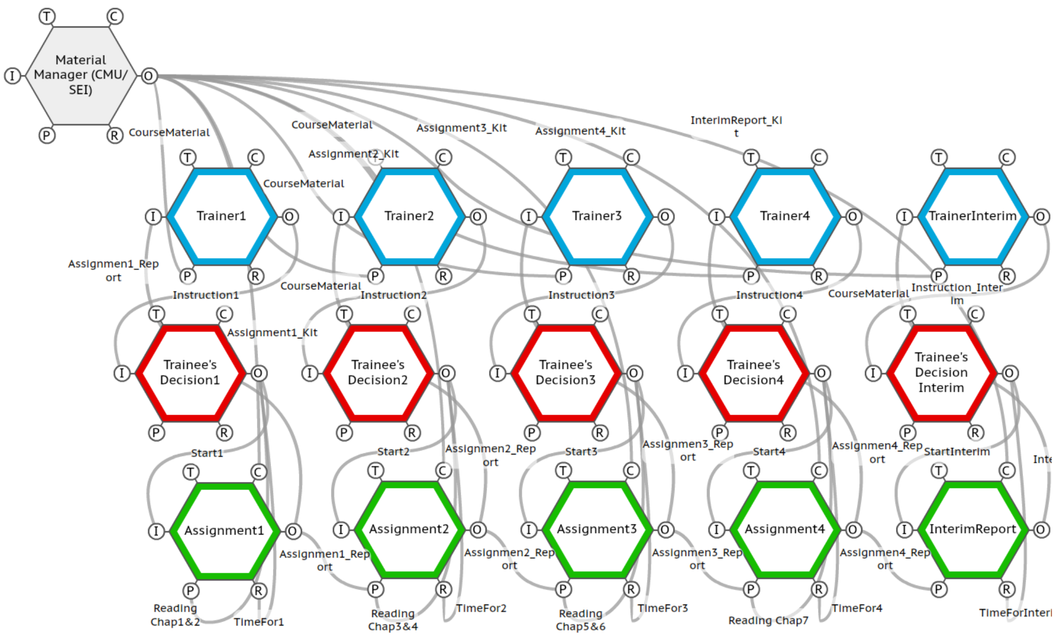

Figure 4 : A holistic FRAM model of PSP for Engineer I

Interactions between functions in the FRAM are represented as connections through

aspects of the FRAM functions. For example, in the model in Figure 4, the function "Trainee's Decision1" has an Instruction1 as an input aspect, which represents an instruction from Trainer1. The function also has "Start1", "TimeFor1", and "Reading Chap1&2" as its output aspects. "Start1" is the permission for starting the assignment 1, and "TimeFor1" time resource allocated for the assignment 1, and "Reading Chap1&2" is the acknowledgement to satisfy the entry criteria for the assignment 1.
We develop hypothetical intervention actions corresponding to the issues based listed above with the FRAM model from instructor's holistic point of view. For example, a potential intervention action, "instructors and lecturers from industry explain the life-long importance of the PSP completion through activities like special workshop and lecture" is listed. This intervention can be an additional control aspect of a Trainee's decision function from the output aspect of an instructor function.

3.4 Modeling in the small

Some issues considered in our improvement are detailed ones while others holistic ones. The FRAM can be also useful in modeling with a detailed view. Trainee's motivation can be changed with instructions at a detailed level. As an example of detailed analysis, we explains a model of the planning phase of the first exercise assignment in PSP0.
A PSP process basically consists of six phases, planning, design, coding, compile, testing, postmortem, as shown in Figure 5. Trainees follow the PSP process when doing the assignment exercise in the course after the lecture of the PSP process.

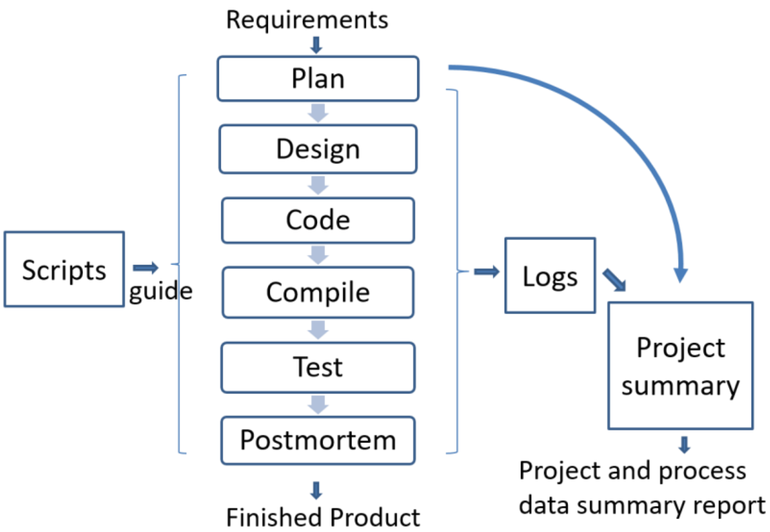

Figure 5 : Overview of the PSP process structure

The PSP course material includes scripts for the course exercises. For example, following is a script for the planning phase of the first assignment.

- Entry Criteria
  - Problem description
  - Project Plan Summary form
  - Time Recording log

- Program Requirements
  - Produce or obtain a requirements statement for the program.
  - Ensure that the requirements statement is clear and unambiguous.
  - Resolve any questions.
- Resource Estimate
  - Make your best estimate of the time required to develop this program.
  - Enter the plan time data in the Project Plan Summary form
- Exit Criteria
  - Documented requirements statement
  - Completed Project Plan Summary form with estimated development time data
  - Completed Time Recording log

Figure 6 shows a FRAM model of the script. For example, the entry criteria in the script corresponds to precondition of a FRAM function and the exit criteria outputs. We analyze FRAM models to develop and improve our instruction scenarios.

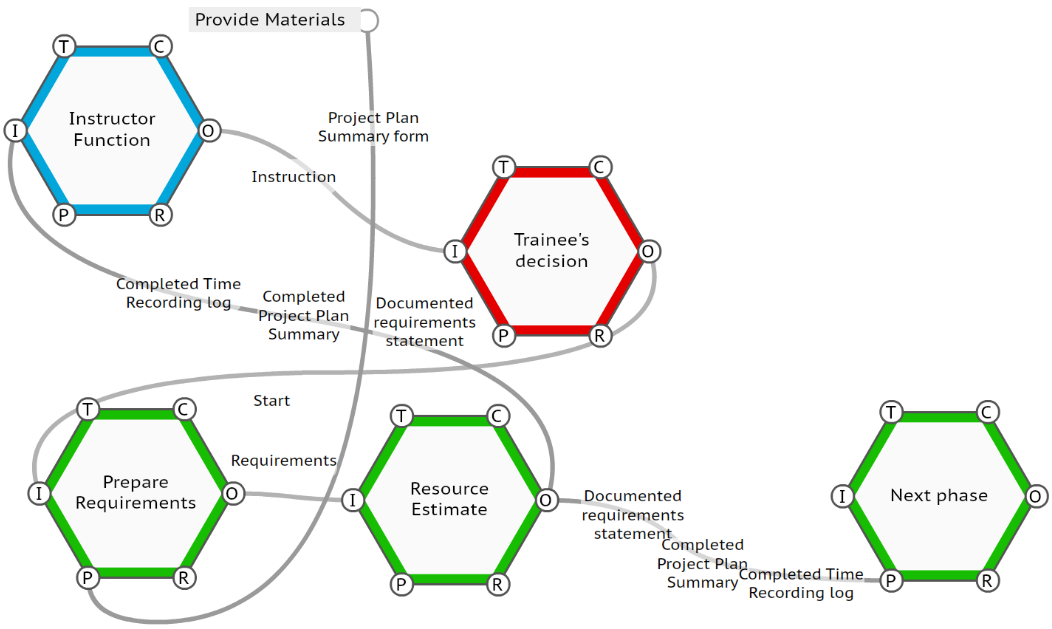

Figure 6 : A detailed FRAM model of the planning script

In the PSP training course, when the work product submitted from a trainee does not satisfy the criteria, the instructor points out the problems and requires resubmission of the work product after the proper correction. In the FRAM model of Figure 6, this pattern corresponds to the loop consisting of the Instructor function, Trainee's decision function, Prepare Requirements function and Resource Estimate function.

From a psychological point of view, if there exist any positive or negative reinforcers in the loop, the motivation process of the trainee will be affected [13]. In a sense, a FRAM model represent a network of functions and activities of the system componets. We can use FRAM models to examine the antecedent and consequence of the motivated behavior like the contingency diagram in applied behavior analysis as shown in Figure 7.

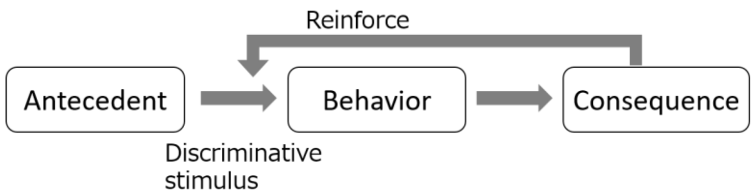

Figure 7: Example of contingency diagram in applied behavior analysis.

In order to analyze the relationships between our scenarios developed with FRAM models and successes and unintended failures during the actual course, we also use GTA that can analyze the phenomena and theories based on qualitative data of the course.

4 Evaluation of Improvement with GTA

As we used a state transition model as a base in modeling the trainee's motivation process, we can view the structure of motivation process shown in Figure 2 as a control-monitor loop like the one as shown in Figure 8.

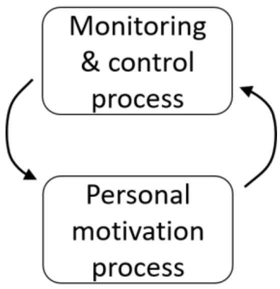

Figure 8 : An abstract view of motivation process in Figure 2.

However, a trainee is not a machine nor computer. Although our course scenarios are artificial artifacts like software programs for a computer system, we cannot check the correctness by using methods for software like software testing. We use a qualitative approach, Grounded Theory Approach, GTA[8][9], to analyze theories in the course to evaluate and validate our scenarios ((4) in Figure 1).

We briefly introduce Grounded Theory Approach, GTA, in this section. GTA is a systematic approach to construct theories and hypotheses through methodical gathering and analysis of data. Firstly, we make interviews and observations to gather data. Then, we write obtained data into sentences, and codify characteristic words into codes to classify and analyze the data. This is a research method that emphasizes obtaining confidence based on data, not just personal impression or intuition.

The common steps of GTA are followings while there exist several variations and no single definition of GTA.

1. Fully understand what you want to analyze, and make sentences from observations and interviews.
2. Eliminate personal thoughts on the data, and divide the text into as many pieces as objectively as possible.
3. Read only each part of the sentence after it has been divided, and give a concise label that appropriately expresses the content. This label should be a concrete concept name with a low degree of abstraction.
4. Next, similar labels are grouped together to create a category that is a superordinate concept and given a name. These operations are called "open coding".
5. A phenomenon is expressed by associating one category with multiple subcategories. A subcategory describes when, where, how, why, etc. about a phenomenon. These operations are called "axial coding".
6. Collect the phenomena created by axial coding and relate the categories. This is the theory that explains social phenomena. This work is called "selective coding".

We also derive properties and dimensions in giving labels in step 3, according to a version of GTA [9]. By examining properties and dimensions, relationships between the Practical-STM, which has factors and state values as shown in Table1, and the result GTA become clearer. We compere factors in the Practical-STM with properties in GTA, and state values with dimensions.

With the intention of analyzing the situation in which changes in the trainee's motivation process occur, we made interviews with the trainees in performing GTA.

Check point
How values in the practical-STM, which may correspond to property dimensions, of trainees change in accordance with the progress of the course scenario.

Gathering data
Semi-structured interviews were conducted with the course attendees focusing on the "trigger of taking the course, the situation during the course, and the prospect of completion".

Coding
We focused on the process and its changes. As characteristic words and phrases, we focused on experience of development process, cost in time, eye opening in terms of team process, difference in teaching method by staff, and so on.

Categories
As the high-level categories, assumed positive items, assumed negative items, unexpected positive items, and unexpected negative items were extracted.

Using these results, we analyzed the scenario from the viewpoint of trainee's motivation. We tried to find problems and unexpected phenomena during our scenarios that have not been noticed up to that point as follows.

- Even though we see no differences at a FRAM model of our scenario, the difference of the implementation of the scenario makes some differences in the trainee's mind. Some differences of methods in assessing and resubmitting assignments caused feeling of unfairness or inefficiency and the feeling degrades trainee's motivation. We noticed the needs of improvement of training environment.
- Trainees had a feeling of losing their way in performing some activities. The PSP course materials are originally developed for industrial level software developers and assume more experience and knowledge than the ordinal students. We need to provide more guidance than those included in the original course materials.

5 Concluding Remarks

We explained our approach to improve instruction scenarios for the PSP training course. The Practical-STM conceptually enables us to formally describe a scenario, a state transition path of the motivation process. However, trainees are not machines nor computers. In order to develop and improve scenarios for human trainees, we used a modeling method of resilience engineering FRAM and a qualitative approach method GTA to analyze causal conditions, intervening conditions, and action strategies in terms of trainee's motivation process. By using the combination of the FRAM and GTA, we can analyze hypothesis and theories for the training course from a view point of trainees motivation process. As our approach is an iterative one, we continue to apply our approach to continuously improve our education.

References

[1] W. S. Humphrey, Introduction to the Team Software Process, Addison-Wesley, 1999.

[2] W. S. Humphrey, TSP - Leading a Development Team, Addison-Wesley Professional, 2005.

[3] W. S. Humphrey, A Self-Improvement Process for Software Engineers, Addison-Wesley, 2007.

[4] K. Ishibashi, M. Hashimoto, M. Umeda, K. Katamine, T. Yoshida and Y. Akiyama, "A preliminary study on formalization of motivation process in personal software process course," Proc. 10th Joint Conference on Knowledge-Based Software Engineering, 2012, pp.128-137.

[5] A. Sakashita, The Research of Organizational Behavior (In Japanese), Hakutou-shobou, 1985.

[6] M. Umeda, K. Katamine, K. Ishibashi, M. Hashimoto, T. Yoshida, "Motivation Process Formalization and its Application to Education Improvement for the Personal Software Process Course," IEICE Transactions on Information and Systems, E97-D, 2014, pp.1127-1138.

[7] E. Hollnagel, FRAM: The Functional Resonance Analysis Method, Ashgate, 2012.

[8] C. Willig, Grounded Theory Methodology in Introducing Qualitative Research in Psychology, Open University Press, 2013, Chapter 7.

[9] J. Corbin, A. Strauss, Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory, SAGE Publications, 2014.

[10] E. E. Lawler, Pay and Organizational Effectiveness: A Psychological View, McGraw- Hill, 1971.

[11] C. S. Holling, "Resilience and stability of ecological systems," Annual Review of Ecology and Systematics, Vol. 4, 1973, pp.1-23.

[12] S. Kusakabe, S. Araki, K. Katamine, and M. Umeda, Analyzing Motivation in Personal Software Process Education Course with a Qualitative Approach. Proc. of 9th International Conference on Learning Technologies and Learning Environments (LTLE2020 / IIAI-AAI 2020), 2020, pp.298-303.

[13] B. Skinner, "Selection by consequences," Behavioral and Brain Sciences, 7(4), 1984, pp.477-481.