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# Changes in Students' Motivation to Study and Their Predictions -Verification of Similarity to Radioactive Decay of Atoms for Changes in Motivation and These Predictive Equations -

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## Abstract

The students' motivation to study in class is presumed to be closely related to their concentration. Previously, we have pointed out the similarity between the temporal variation of the motivation to study and the radioactive decay process. (A) In this paper, we attempted to verify the radioactive-decay approximation for the students' motivation. We also examined the validity for the predictive equation to describe the motivation. (B) For these verifications, we used data from 2022 and 2023 academic year. As a result, although there remains some degree of uncertainty in the approximation using continuous functions (including decay functions), we confirmed that the assumption of the radioactive-decay approximation is valid for the entire flow of ten sessions. It is also noted that the accuracy of the assumption of the radioactive-decay approximation is found to be higher than that of the linear approximation for only the six classes in the present study. Furthermore, we conclude that the formula for predicting radiative decay derived by the method we have found are valid to some extent. This implies that motivation level to study follows a natural law.
*Keywords:* concentration, comprehension, decay function, classroom improvement

## 1 Introduction

We, faculty members, often feel that students' concentration and comprehension level decline as time passes from the start of sessions at universities. The same thing happens as the number of classes in university increases.

Similarly, a decrease in the number of views of popular YouTube videos (It seems to be related to their popularity) has been observed as time passes [1, 2].

We considered that predicting subsequent values for students’ concentration and comprehension level in the early stages of session of classes would be useful for making appropriate modifications of teaching methods, speed and content of future sessions.

The aim of this study is to predict the time variation of concentration and comprehension level of students in each class. We considered that, for these quantities, there exists a mechanism analogous to the radioactive-decay of atoms, whereby 'the amount of change occurs in proportion to the amount that is present' (hereafter referred to as 'the assumption of the radioactive-decay approximation'). Various measurement methods have been proposed for concentration, comprehension, etc., each with their own merits and demerits [3-8].

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We focus on “motivation to study” (hereafter referred to as MS) in session of class (Yarukido in Japanese) [9, 10], which is presumed to be strongly related to concentration.

In our previous studies [11,12], using data from three liberal arts classes in the first semester of the 2022 academic year, the authors devised a method and derived a predictive equation to predict the motivation level from the next session onwards by entering the motivation level at the start of the first class.

In this paper, we attempt to verify "(A) the verification of the assumption of the radioactive-decay approximation" based on the data for the 2022 academic year used in the previous paper and the data for the 2023 academic year newly added this edition, and "(B) the verification of the radioactive-decay approximation predictive formulae we devised" under the condition that (A) has been verified.

In verifying the above two, a comparison with the linear approximation is also be made.

This paper is written in the following order. We attempt to confirm the verification of the assumption of the radioactive-decay approximation (A) in Chapter 2.

Then, we explain the process of deriving the approximate prediction formula for radioactive decay and verify the validity of the prediction (B) in Chapter 3. Chapter 4 is devoted to summary.

# 2 Verification of the Assumption of the Radioactive-decay Approximation

## 2.1 The assumption of the radioactive-decay approximation for motivation

We assumed that the mechanism of changes in the overall MS of students in a class is similar to natural phenomena such as the decay of radioactive atoms. The differential equations are as follows [13, 14].

$$\frac{\mathrm{d}\varphi(t)}{\mathrm{d}t} = -a\varphi(t) \ \ (a > 0) \qquad \text{(Eq. 1)}$$

Where ’$\varphi$ ($t$)’ is ‘motivation level (0-100%)’, ‘$t$’ is time and ‘$a$’ is a constant. It follows as in solving Eq. 1:

$$\varphi(t) = A\exp(-at) \qquad \text{(Eq. 2)}$$

The integration constant ‘$A$’ is a quantity determined by the initial value at the first session, and ‘$a$’ is a quantity representing the attenuation rate of the MS. Further, (Eq. 2) is modified as follows,

$$\varphi(t) = A\exp\{-a(t-1)\} \qquad \text{(Eq. 3)}$$

Here, in order to read $t$ as the number of sessions, "$t$" in (Eq.2) was replaced with "$t$-1". The above equation is hereafter referred to as the "radioactive decay approximation equation".

## 2.2 The MS (motivation to study)

By using the 'Motivation Check Sheet' (hereinafter referred to as 'the questionnaire'), which has been proposed by the authors in the literature [9] to support the improvement of metacognitive skills, the 'motivation level' of the students is surveyed for all attendees in each session. The questionnaire contains four quantitative indicators.

1. Motivation at the start of the session（0-100%）to evaluate

2. Motivation at the end of the session （0-100%） to evaluate

3. Comprehension at the end of the session 5-level rating

4. Satisfaction at the end of the session 5-level rating

5. Impressions of the session, etc. (free text)

## 2.3 Data collection

Data were collected in courses offered in the spring semester of the first year in liberal arts at K University for the academic years 2022 and 2023. The status of each class is shown in Table 1. At the beginning of each class, all students fill out the check sheet form at the start and the end of their sessions from the first session to the tenth session to indicate their motivation. For more details, see the literature [12].

Table 1. List of Survey Courses

| Class | Academic year | Subject | Required? | Students | Valid answer |
|---|---|---|---|---|---|
| X | 2022 | Basic information processing 1A | Required | 29 | 21 |
| Y | 2022 | Basic information processing 1B | Required | 25 | 21 |
| Z | 2022 | Basic statistics | Elective | 16 | 15 |
| K | 2023 | Basic information processing 1A | Required | 21 | 19 |
| L | 2023 | Basic information processing 1B | Required | 20 | 18 |
| M | 2023 | Basic mathematics | Elective | 21 | 18 |

## 2.4 Verification of the assumption of the radioactive-decay approximation

The methods are as follows.

The MS of these six classes was measured every time, and the average value was calculated for each class. Based on all the measured values (ten sessions), an approximate formula for radioactive-decay was calculated by the least-squares method. These actual data are compared with the approximate formula to determine the error.

Each error is determined by comparing these measured values with a value determined by a linear approximation formula using the least-squares method based on all of the measured values. The curve or straight line by either approximation is set to pass through the measurements taken in the first session.

The two approximate formulae by the least-squares method for each class and the per-approximation error are given in Table 2.

Table 2. Comparison of errors for the approximation formulae

| Class | Radioactive decay approximate expression | Error on the left (pt.) | linear approximate expression | Error on the left (pt.) |
|---|---|---|---|---|
| X | $\varphi(t)=74.821\exp\{-0.018(t-1)\}$ | 4.105 | $\varphi(t)=-1.385t+76.206$ | 4.196 |
| Y | $\varphi(t)=71.304\exp\{-0.017(t-1)\}$ | 2.032 | $\varphi(t)=-1.151t+72.455$ | 2.011 |
| Z | $\varphi(t)=67.667\exp\{-0.021(t-1)\}$ | 1.502 | $\varphi(t)=-1.305t+68.972$ | 1.548 |
| K | $\varphi(t)=73.556\exp\{-0.023(t-1)\}$ | 3.631 | $\varphi(t)=-1.547t+75.103$ | 3.772 |
| L | $\varphi(t)=70.556\exp\{-0.043(t-1)\}$ | 5.626 | $\varphi(t)=-2.252t+72.808$ | 6.078 |
| M | $\varphi(t)=66.235\exp\{-0.008(t-1)\}$ | 2.739 | $\varphi(t)=-0.496t+66.731$ | 2.752 |
| Ave. | | 3.272 | | 3.393 |

The average errors for the all six classes are 3.3 points and 3.4 points for the radioactive-decay approximation and linear approximation, respectively. From this, it can be seen that with regard to the errors in the six-class average, those of both approximations are comparable, or the radioactive-decay approximation is slightly more effective. The breakdown is that the radioactive-decay approximation is more effective for the four classes, while both approximations are comparable for the other two classes. Since the current data consists of only six classes, there is no noticeable difference for errors between the two approximations. Therefore, it still has to be argued that the radioactive-decay approximation is statistically more effective than the linear approximation. However, the fact that the radiative-decay approximation is even slightly more effective than the linear approximation seems to imply that the mechanism of MS is not mechanical but follows natural laws.

We conclude from the present analysis that "it is reasonable to fit the radioactive-decay approximation to changes in MS. Further detailed investigation is required, but this will be our future work. The fact that the measured values rise and fall significantly at each time is due to the fact that the number of people as a sample is much smaller than the number of atoms as in radioactive decay, and that there are only about ten sessions per semester. This means that observational errors should be taken into account when considering each round of motivation as a radioactive decay. In other words, methods of increasing observation frequency and shortening observation intervals also need to be considered.

However, an overall trend towards attenuation could be demonstrated. Since the value of the power of the exponential function in the radioactive-decay approximation formula is extremely small, the difference between the radioactive-decay approximation and the linear approximation using the regression line used for comparison is not large.

## 3 Verification of the Validity of the Adoption of the Radioactive-decay Approximation Prediction Equation

Since we were able to show that the radioactive-decay approximation reproduces the data well, we try to find a universal formula that predicts this.

### 3.1 Methods for obtaining radioactive decay approximation predictive equations

The predictive equation is derived using individual student data for three classes in 2022.

For individual students, there are three patterns of change in MS: increasing, constant and decreasing with the number of sessions. In this study, we use data with decreasing pattern, as the aim is to predict the MS in a declining class (group). The data for individual students in the decreasing pattern is shown in the scatter diagram (Fig. 1). The correlations of motivation level between the first and tenth sessions are shown in Table 3.

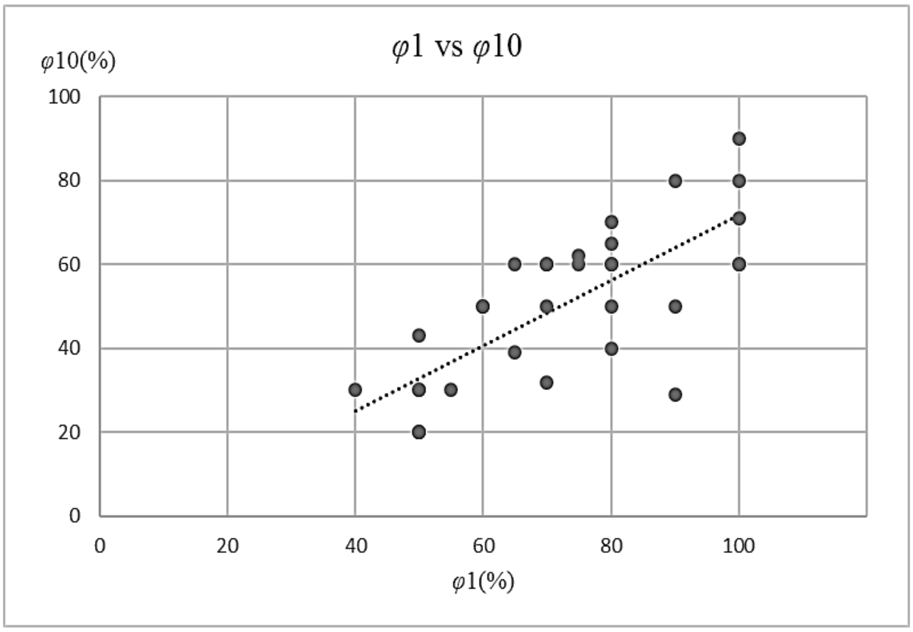


Figure 1: Correlations between motivation levels in the first and tenth class sessions

Table3: Correlation coefficients and regression lines

| Correlation coefficient | Regression line |
|---|---|
| 0.68 | $\varphi 10 = 0.776\varphi 1 - 6.067$ (Eq. 4) |

*The $\varphi$ without brackets after it represents the measured value, while the number immediately after it represents the class sessions.

These results show that there is a rather strong positive correlation between the motivation levels of the first and tenth sessions. Using the regression lines shown in Fig. 1 and Table 3, we find that inputting the motivation level of the first session ($\varphi 1$) can predict that of the tenth session ($\varphi 10$). Thanks to this, it is possible to predict the results of the tenth session by inputting the motivation level of the first session using the regression line shown in Figure 1 and Table 3.

## 3.2 Determination of the radioactive decay approximation predictive equation

By substituting the numerical value of the motivation level in the first class, '$\varphi 1$', into Eq. 4 the motivation level in the tenth session, '$\varphi 10$', can be calculated. Then, two points are determined, and the coefficients "$A$" and "$a$" in (Eq. 3) can be determined respectively, completing the predictive equation for the entire class. The equation is therefore as follows.

$$\varphi(t) = A\exp\{-a(t-1)\} \qquad \text{... (Eq. 3)}$$

$$A = \varphi 1 \qquad \text{... (Eq. 5)}$$

$$a = \ln\{(0.7764\varphi 1 - 6.067)/\varphi 1\}/(-9) \qquad \text{... (Eq. 6)}$$

### 3.3 Verification of the prediction equations by the radioactive-decay approximation

We verify the validity of the radioactive-decay approximation predictive equation derived from Eq. 3, 5, and 6. The per-occurrence errors with the values from the radiative-decay approximation predictive equation or with the values from the linear approximation predictive equation are shown in Table 4.

Table 4: Comparison of errors according to the predictive equations

| class | Radiative decay approximation predictive equations (same as Table 2) | Error on the left (pt.) | Linear approximation predictive equations | Error on the left (pt.) |
|---|---|---|---|---|
| X | $\varphi(t)$=74.821exp{-0.040($t$-1)} | 6.392 | $\varphi(t)$=-2.452$t$+77.273 | 5.933 |
| Y | $\varphi(t)$=71.304exp{-0.041($t$-1)} | 6.666 | $\varphi(t)$=-2.347$t$+73.651 | 5.621 |
| Z | $\varphi(t)$=67.667exp{-0.042($t$-1)} | 5.303 | $\varphi(t)$=-2.239$t$+69.905 | 4.378 |
| K | $\varphi(t)$=73.556exp{-0.041($t$-1)} | 5.303 | $\varphi(t)$=-2.414$t$+75.970 | 4.931 |
| L | $\varphi(t)$=70.556exp{-0.041($t$-1)} | 5.632 | $\varphi(t)$=-2.325$t$+72.880 | 5.998 |
| M | $\varphi(t)$=66.235exp{-0.042($t$-1)} | 8.550 | $\varphi(t)$=-2.196$t$+66.731 | 7.515 |
| average | | 6.308 | | 5.729 |

The average errors for the entire six classes are 6.3 points for the radioactive-decay approximation predictive equation and 5.7 points. for the linear approximation predictive equation. Therefore, it can be said that the linear approximation formula has more predictive power than the radioactive-decay approximation prediction formula with regard to the six-class average error. As a breakdown, the linear approximation predictive equation is more effective for five classes, while the radioactive decay approximation predictive equation is more effective for the remaining one class.

This result may be due to the fact that the curve was approximated by passing through two points. However, it turns out that the linear approximation is also quite effective.

However, the results of the previous chapter indicate that the assumption of the radioactive-decay approximation is valid for change of motivation level. For this reason, the formulae derived by the radioactive-decay approximation are discussed below.

The aim of this study is to predict an equation that is as close as possible to the radioactive -decay approximation derived from all the data using the least-squares method.

The six-class average values of the errors are 3.3 points for the approximate equations and 6.3 points for the predictive equations, with the error of the predictive equation being approximately twice that of the approximate equation.

Based on the results in Chapter 2, the best of the continuous functions in this study are the radioactive-decay approximation equations in Table 2. Even with these approximate formulas that are considered ideal, there is an error of about 3.3 points. We consider that an error of 6.3 points in the prediction formula is not a bad result.

It should be noted that, despite the fact that the radioactive decay approximation formula is more effective than the linear approximation formula, as discussed above, the linear prediction formula is more accurate than the radioactive-decay prediction formula.

As mentioned in Chapter 2, observation errors have a significant impact here. It is necessary to reduce the observation error and verify the reasons for this, but a system for this purpose is currently under development.

## 4 Summary

In this paper, we attempted to verify the validity of the radioactive-decay approximation for temporal changes in motivation to study (A), which is presumed to be strongly related to concentration, and then the validity of the predictive equation for the decay function derived from the first session of motivation level that we found (B). For these verification, we used the 2022 and 2023 academic year data.

The results for (A) are as follows. The number of people in the classes as a sample is much smaller than the number of atoms as in radioactive decay, and the motivation has a certain amount of vertical variation due to the fact that the session variation is a discontinuous value with a large width of times, which cause a large error. Despite this, it was confirmed that the assumption of the radioactive-decay approximation would be valid to some extent for the flow of ten sessions as a whole.

It was also found that the accuracy of the radioactive-decay approximation is higher than that of the linear approximation only for the six classes in the present study.

For (B), the results are as follows. We conclude that the radiative-decay predictive equation is reasonable. However, when considering the prediction formula, a straight line passing through two points is considered, so the linear prediction formula shows higher predictive power than the radioactive decay prediction formula.

To improve these issues, we are currently building a system to increase observation frequency and shorten observation intervals.

We consider the individual MS to be an uncertain natural phenomenon, similar to natural phenomena such as the radioactive decay of individual atoms. Therefore, in this study, it was not possible to predict the individual MS, but rather we attempted to predict the MS as a group, that is, as a macro. In addition, since the conditions of individual classes vary widely depending on the subject situation, teacher's ability, teaching method, etc., in this study, we selected a technical analysis method rather than a fundamental analysis method as used in stock investment.

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[Note 2]
The study was authorized for implementation following research ethics review at Koshien University.

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