Preparing 21\textsuperscript{st}-century teacher candidates through embryology learning with technological pedagogical and content knowledge (TPACK) framework

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Abstract. This study is aimed at discovering the effectiveness of Technological Pedagogical and Content Knowledge (TPACK) framework in establishing master of Embryology concepts and 21\textsuperscript{st} century teachers’ characteristics on students of Biology teacher candidates. The representation of Embryology learning materials were changed into the form of interactive multi-media uploaded on Learning Management System (LMS) Moodle which could be accessed through the internet. The learning taking place using blended learning method was attended by 49 students. The measurement of dependent variables were conducted through LSM and in-class direct observation. The result of the study shows that learning using TPACK framework can enhance the mastery of Embryology concepts significantly (pretest $X = 7.35$, posttest $X = 15.35$, $t_{(48)} = 0.74$, $p < 0.05$); and effective in building the character of 21\textsuperscript{st}-century teacher candidates who have 21\textsuperscript{st}-century skills.

1. Introduction

Technological Pedagogical and Content Knowledge (TPACK) is a framework of a learning approach that combines the seven components of knowledge into a single context of the learning program, that is Content Knowledge (CK), Pedagogical Knowledge (PK), Technology Knowledge (TK), Pedagogical Content Knowledge (PCK), Technology Content Knowledge (TCK), Technology Pedagogical Knowledge (TPK), and various solutions within certain learning contexts [1,2].

Since it was developed in 2006 [1], TPACK has grown and been known worldwide. Research and development concepts of TPACK continue to this day mainly in two major categories, namely the discussion and refinement of TPACK’s theoretical foundations, and the handling of practical problems of professional teacher measurement and development [2], as well as on strategy development, approaches and training methods to develop and improve TPACK knowledge/skills of in service and pre service teachers [3,4,5], development of assessment instrumental and the implementation of measurement and analysis of TPACK knowledge/skills of in service and pre service teachers [6,7], and exploration of college lecturers’ perceptions in TPACK applications in the future [8, 9]. Specifically for assessing TPACK teachers in designing learning with technology, instruments covering five criteria have been developed [10], namely 1) identification of topics taught by technology, such as topics that are difficult to understand or difficult to teach effectively in the classroom; 2) identification of representation to change the content taught into a form that the learners...
can understand, and difficult to support in traditional ways; 3) identification of teaching strategies, which are difficult or impossible to implement in a traditional way; 4) selection of appropriate computer equipment and effective use of pedagogy; and 5) identification of student-centered learning strategies, appropriate to be combined with technology.

Based on the review of the results of the study it is apparent that there is still a lot of research and works that can be done in the improvement of TPACK framework and its implementation in various learning contexts at both primary and secondary levels as well as at university level. One of the less-studied gaps is the learning effect that implements TPACK framework to students’ learning outcomes. More specifically, studies on the effectiveness of learning using TPACK framework in the context of embryological learning have not been identified.

The implementation of the TPACK framework in the context of Embryology learning in this study is intended to help address the difficulty of biology teacher candidates in learning and mastering Embryology concepts through the provision of opportunities to more easily obtain information on teaching materials, and learning opportunities both independently and in real learning communities. The characteristics of the seven TPACK components [1,2] and five assessment criteria of TPACK’s teachers in designing learning with technology [10] are examined and met, and then mixed into a semester learning program.

Learning with the implementation of TPACK framework for prospective teachers is a means of preparing teachers for 21st century learning [9]. Through the study with the application of TPACK framework, it is expected to generate teacher candidates who meet the characteristics of qualified teachers to be able to carry out the 21st century learning, which have the characteristics of ‘adventurer’, ‘resilience’, as well as have creative and problem solving skills [11]. This expectancy can be met as the Embryology learning with the implementation of TPACK framework is designed to fulfill six key elements of the coaching of 21st century learning, which are: 1) emphasis on core points, 2) emphasis on learning skills, 3) using 21st century tools to develop learning capabilities, 4) teaching and learning in the context of the 21st century, 5) teaching and learning contents of the 21st century, and 6) using 21st century assessments that measure 21st century skills [12]. In its implementation, this learning also hones the 21st century skills of the students, which includes communication and collaboration, problem solving, creativity and innovation, through the literacy of the digital age, inventive thinking, effective communication, and high productivity [12].

The blended learning method in the Embryology learning with TPACK framework give the students opportunities to utilize and increase digital literacy in the context of online learning which covers media literacy, information literacy, technological literacy [12] and independent learning as well [13]. However, the context of in-class meetings give experiences for the students to learn in the real learning community by socializing, communications, collaborating, exchanging information, and establishing critical and creative ways of thinking in solving problem [14], as well as giving opportunities for self-actualization [15].

In this study, communicative and collaborative competences and also the establishment of critical and creative ways of thinking in problem solving are honed through discussion of embryology-related problems and presentations in small groups during in-class meetings. The measurement of these skill ownership is represented as the assessment of communicative assessment in discussions. Other characters as the foundation of the criteria fulfillment of qualified teachers [11] are represented in discipline, learning independence, and curiosity or learning enthusiasm.

2. Method
The overall assembly of the TPACK components produces an Embryology learning program in an academic semester. By applying informatics technology, the representations of the Embryology main subjects are transformed into an interactive multimedia form, which is then uploaded into LMS Moodle so that the students can access them via the internet. In the implementation of the learning, 49 students involved in the Embryology learning are given independent learning tasks by accessing and studying each subject in the teaching materials through the website of bio.elearning.unpas.ac.id for
one week before an in-class meeting. The activity and progress of independent learning outcomes, as well as the character of the discipline are monitored directly through the LMS.

Embryological concept mastery measurement is done on each subject through test before learning (pretest) and after learning (posttest). The implementation of the tests takes place through LMS Moodle that lets students and lecturers know the results shortly thereafter. The mastery of the Embryology concepts as a learning effect by applying the TPACK framework is illustrated from the level and category of changes that occur between the pretest and posttest result scores. The significance of change in the mastery of Embryology concepts is determined with the help of the SPSS (Statistical Product and Service Solution) version 23, through the T-test when the data are normally distributed, and Mann Whitney U test when the data are not normally distributed.

Discussions, confirmation, verification practice, assignment, and strengthening of understanding are held in in-class meetings so that learning objectives are achieved. The discussion is conducted in groups each consisting of 5 persons. The results of the group discussions are then presented to get the response of the whole class. The characteristics of learning independence, learning enthusiasm, and activities in discussions are assessed during in-class learning. Assessment is done by scoring using the rating scale method 1 through 4. Score 4 is an excellent category, 3 good, 2 enough, and 1 poor. Each category for each of the assessed variables is translated into definitions as outlined in the rubric. The obtained data, both through LMS monitoring and observations during in-class learning, were collected during the embryology learning program. The ownership of the students' character values is determined at the end of the semester by summing up the scores and determining the average value, then the category is defined for each character value. The effectiveness level of Embryology course learning on character building is determined based on the average score of character values: 3.1 - 4.00 = high effectiveness; 2.1 - 3.00 = moderate effectiveness; 0 - 2.00 = low effectiveness.

3. Result and discussion

3.1. The mastery of embryology concept

The measurement result shows that the mastery of the Embriology concepts on any main subjects on average increase significantly on moderate to high category.

Table 1. The recapitulation of significance analysis of changes in the mastery of the embryology concepts on each main subject.

| No. | Main Subjects                      | Pre-test | Post-test | Gain | Significance of changes (t-test)          |
|-----|------------------------------------|----------|-----------|------|------------------------------------------|
| 1   | History and Development of Embryology | 7.31     | 16.36     | 9.05 | increased significantly                   |
| 2   | Reproductive Organs                | 8.51     | 17.53     | 9.02 | increased significantly                   |
| 3   | Neurohormonal Regulation           | 8.86     | 17.63     | 8.77 | increased significantly                   |
| 4   | Spermatogenesis and Oogenesis      | 7.26     | 16.68     | 9.42 | increased significantly                   |
| 5   | Fertilization                      | 9.07     | 19.01     | 9.94 | increased significantly                   |
| 6   | Cleavage and Blastulation          | 6.29     | 18.84     | 12.55| increased significantly                   |
| 7   | Gastrulation                       | 7.24     | 14.71     | 7.47 | increased significantly                   |
| 8   | Organogenesis                      | 4.27     | 13.41     | 9.14 | increased significantly                   |
|     | Average                            | 7.35     | 15.53     | 8.18 | increased significantly                   |

On the main subject of History and Development of Embriology, the significant increase of the concept mastery occurs from the average pretest score ($\bar{X} = 7.31$) to the average posttest score ($\bar{X} = 16.36$), $t_{(46)} = 0.973, p < 0.05$. The data show that the implementation of TPACK framework quite helps the students overcome difficulties in understanding the development of scientists' thoughts that generate basic ideas of Embriology, for instance epigenesist theory, the development of chicken
embryo, the theory of cells, the characteristic differences of germ cells and somatic cells, and mosaic theory or core determination, as well as induction theory [16, 17, 18, 19].

The subject of the Reproductive Organs discusses the anatomical and histological structures of male and female reproductive organs in five animal classes [16, 17, 18, 19]. Learning by implementing the TPACK approach as well as the depth and breadth of the presentation presented may increase the mastery of these concepts as indicated by the significant increase (pretest score $X = 8.51$; post test score $X = 17.53$; $t_{(48)} = 0.001$, $p < 0.05$). On the main subject of the Neurohormonal Regulation, it discusses the mechanism of regulation of nerves and hormones on the synergistic function of the reproductive organs so as to produce hereditary products [16, 17, 18, 19]. The concept master of Neurohormonal Regulation after learning using TPACK framework increases significantly (pretest score $X = 8.86$; posttest $X = 17.63$; $t_{(48)} = 0.982$, $p < 0.05$). The main subject of the Gametogenesis: Spermatogenesis and Oogenesis discusses the processes that take place during the formation of spermatozoa in the testes, and the egg cells in the ovaries [16, 17, 18, 19]. The TPACK framework improves the mastery of these concepts significantly (pretest score $X = 7.26$, posttest $X = 16.68$; $t_{(48)} = 0.917$, $p < 0.05$). Similarly, the situation on the main subject of Fertilization, increased knowledge after learning using TPACK framework occurs significantly (pretest score $X = 9.07$, posttest $X = 19.01$, $t_{(48)} = 0.986$, $p < 0.05$). The subject of Fertilization describes in detail the mechanisms of spermatozoa and egg travel ahead of the encounter, the penetration of spermatozoa into the egg, to the fusion of male pronucleus from the spermatozoa and the female pronucleus from the egg form a zygote nucleus [16, 17, 18, 19].

In contrast to the pre test scores on the previous subjects, the average pretest score on the Cleavage and Blastulation subject was low, i.e. $X = 6.29$. This main subject is one of the core subjects of Embryology that relatively few students acquired the subject in the previous course. This subject begins to be complicated and challenging for the students to understand it. It describes the cleavage process of zygotes from one cell to a collection of smaller-sized blastomer cells, called morula, which then becomes blastula with the formation of fluid-filled space (blastosul) between the collections of blastomer cells. The beginning cleavage process of takes place with different patterns in each animal class, depending on the distribution pattern of egg yolks contained in the egg before fertilization [16, 17, 18, 19]. Learning by implementing TPACK framework seems to help overcome the students' difficulties in understanding Cleavage and Blastulation concepts. The mastery of this concept is increased significantly (posttest $X = 18.84$; $t_{(46)} = 0.933$, $p < 0.05$). The subject of Gastrulation is the material that describes the continuation processes of cleavage and blastulation, so difficulties will arise for students who study it when the mastery of the concept of cleavage and blastulation is not sufficient. On the subject Gastrulation, the reorganization processes of blastomer cells in the blastula to form embryos with three layers of germinativum are described [16, 17, 18, 19]. The study of the Gastrulation subject using TPACK framework implies a significant change in conceptual mastery (pretest $X = 7.24$, posttest $X = 14.71$, $t_{(46)} = 0.945$, $p < 0.05$). The obtained pretest score on the subject of Organogenesis is very low, which is $X = 4.27$. This subject presents the mechanisms underlying the change of each gastrula germ layer of various animal species, to the production of new organs [16, 17, 18, 19]. The difficulty of studying and mastering organogenesis concepts seems relatively manageable through learning by applying the TPACK framework. The results of the measurement at the end of the learning show a significant improvement in the mastery of the concept (posttest $X = 13.41$; $t_{(46)} = 0.933$, $p < 0.05$).

Overall, the results of this study indicate that through learning using TPACK framework, the mastery of Embryology concepts is significantly improved (pre test $X = 7.35$, post test $X = 15.53$, $t_{(7)} = 1.000$, $p < 0.05$). Because the TPACK framework is a complex interaction of the seven knowledge components (CK, PK, TK, PCK, TCK, TPK, and TPACK), this increase in learning outcomes is a combined effect of each strength and weakness of each component. Therefore, the success of learning with the TPACK framework highly depends on the accuracy of determining the type of elements of each component being combined.
3.2. The development of character values

Overall, the effectiveness of Embryology learning with the approach of TPACK framework toward the development of character values of discipline, learning independence, learning enthusiasm and being communicative in the discussion are presented on Table 2.

Self-discipline can be developed personally as a strong desire to meet his/her own rules to achieve particular targets that he/she wants. In this study, the applied rule is the access of teaching materials through the web within a week before in-class learning. Students of the research subjects who demonstrate their self-discipline to achieve learning objectives will access the teaching materials since the longest time within the set time span, thus they have more learning opportunities. Conversely, accessing the materials closer to the set end time indicates lesser discipline. The result of the observation shows that the students, access the teaching materials within the period of 2 to 5 days before the day of in-class learning, so that the average score is as shown in Table 2, namely 2.79. Thus, the learning that is compatible with the TPACK framework can be categorized as moderate.

| Character Values | Main Subjects of Embryology Courses | Avg. Effectiveness | Category |
|-----------------|-----------------------------------|-------------------|----------|
| Discipline      | 3.00 2.98 2.92 2.73 2.77 2.75 1.60 2.23 2.79 | moderate         |
| Learning independence | 3.00 4.00 4.00 2.56 3.23 3.58 3.00 2.00 3.11 | high              |
| Learning enthusiasm | 3.00 2.77 3.33 3.73 3.33 4.00 3.33 3.00 3.31 | high              |
| Communicative competence in discussions | 3.27 3.80 3.35 3.80 3.35 3.35 3.48 3.40 3.37 | high              |
| Average         | 3.07 3.28 3.40 3.12 3.20 3.43 2.85 2.66 3.13 |                   |

Note:
1 = History and Development of Embryology
2 = Reproductive Organs
3 = Neurohormonal Regulation
4 = Gametogenesis: Spermatogenesis & Oogenesis
5 = main subject of Fertilization
6 = main subject of Cleavage and Blastulation
7 = main subject of Gastrulation
8 = main subject of Organogenesis

Independence is one of the foundations for building the characteristics of qualified teachers to be able to implement 21st century learning. With the character of high independence, the ‘adventurer’ and ‘resiliance’ can be more easily built. An ‘adventurer’ character can independently accept changes, seek new challenges, take risks, have resilience to fears, physically and intellectually continue searching and extending teaching knowledge and advocacy for both themselves and for learners, and build and strengthen their professional identities [11]. In addition, those with high independence can easily build ‘resiliance’, which is an adaptive response to stress, challenging situations, and changes that occur in the work environment and life, and have high self-efficacy and confidence. In this study, the aspect of independence is focused on the students’ learning independence, particularly in terms of learning behavior in in-class learning. A good level of learning independence is indicated by learning, listening, seeing, taking notes and determining questions or arguments on their own initiatives. The observation result shows that the study of Embryology with TPACK framework effectively helps build the character value of students’ learning independence in high category (average score of 3.11). It seems that learning independence is influenced by the complexity of the main subjects and the clarity of IM which represent the teaching materials.

Like learning independence, the higher the character of learning enthusiasm is, the stronger the development of the ‘adventurer’ and ‘resiliance’ characteristics is. In addition, enthusiasm will also support the development of the character of discipline and learning independence, so that it will result
broad and deep knowledge in turn. The observation result shows the students’ learning enthusiasm the study subjects is classified as good in learning each main subject with the average score of 3.31. Therefore, it can be said that the Embryology learning with the TPACK framework is effective to develop the students’ learning enthusiasm in high category.

The communicative competence in discussions is a representation of communication and collaboration skills [12]. In this study, communication and collaboration skills were built during group discussions and classroom presentations. Measurements are made on the quality, quantity and suitability of ideas, arguments, and/or questions with the contexts of the subjects. It seems that being armed with the knowledge gained in advance through e-learning, as well as the spirit of learning in the real learning community, it encourages the students to be active in group discussions and class discussions when entering presentation sessions. The results of the measurements in the observations show the score of communicative competence in discussions on the good category for all subjects, with an average score of 3.28. Therefore, the effectiveness of Embryology learning with TPACK framework is on high category to build communicative competence in discussions.

4. Conclusion
Based on the result of the present study, it can be concluded that the learning of Embryology with the TPACK framework can significantly enhance/improve mastery of Embryology concepts of Biology teacher candidates on high category and it is highly effective in establishing/building characteristic values of 21st century teacher candidates on learning independence, learning enthusiasm, and communicative competence in discussions, and the moderate level of effectiveness is building the character of discipline.

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