STEM-SPORT STUDENT WORKSHEET BASED ON *PENCAK SILAT* LOCAL WISDOM ASSISTED BY AUGMENTED REALITY TO IMPROVE SENIOR HIGH SCHOOL STUDENTS' CRITICAL THINKING AND COLLABORATION ABILITIES ON ROTATIONAL DYNAMICS MATERIAL

Wipsar Sunu Brams Dwandaru[2] and Febriani[1]

[1,2] *Faculty of Mathematics and Natural Sciences, Universitas Negeri Yogyakarta, Colombo Street Number 1, Yogyakarta, Indonesia*

ABSTRACT

Critical thinking and collaboration skills are necessary to face the challenges of the 21st century. The purpose of this study is to determine the effectiveness of Science, Technology, Engineering, Mathematics – Sport (STEM-S) student worksheets based on local wisdom *pencak silat* assisted by Augmented Reality (AR) to improve critical thinking and collaboration skills on rotational dynamics material. The method used in this research is experiment. The design used is quasi-experimental design with pretest-posttest control group design approach. The classes used amounted to three classes of XI MIPA, consisting of two experimental classes and one control class. The product developed is in the effective category based on descriptive analysis of observation results of collaboration skills. The multivariate tests provide the results of the influence of the class on critical thinking skills and collaboration simultaneously. In the multivariate follow-up test, the critical thinking posttest variable produces a significant influence between experimental class 1 and experimental class 2 as well as experimental class 1 and the control class.

Keywords: STEM-S student worksheets, *Pencak silat* local wisdom, Rotational dynamics, Critical thinking skills, Collaboration skills.

INTRODUCTION

Critical thinking and collaboration skills are part of the 4C skills. This combination of cognitive and affective skills is needed to face the challenges of the 21st century. Each skill has an important role and needs to be cultivated by the younger generation via various efforts. However, both abilities still need to be improved among Indonesian students as the younger generation (Khoiri et al., 2021). This requires various efforts through learning innovations to improve these abilities among students. This effort can be done through learning activities. One of the learning activities that can be utilized for its potential in fostering 4C skills is physics learning (Hidayatullah et al., 2021).

There are various challenges in the learning process that make the potential of physics cannot be utilized optimally. This is because physics has been more inclined to calculations and mathematical formulas (Owen et al., 2008; Ekici, 2016). Physics is also considered as an abstract subject because the learning process is not directly related to everyday life (Suzuk et al., 2011; Guido, 2013). This causes the role of physics and its relation to natural phenomena becoming significantly invisible.

One of the physics subjects that can be optimized for its potential is rotational dynamics. Rotational dynamics is one of the subjects that has a close relationship with various everyday life activities. This subject can become the basis for studying various natural and surrounding phenomena. Some examples of the application of rotational dynamics, e.g.: futsal in sports (Purwanto & Khurrom, 2022), transportation (Celis et al., 2020), and the art of ballet (Furtado et al., 2020).

However, there are still various things that make the optimization process on rotational dynamics material hampered. This is based on research by Takus et al. (2021). This study analyzes the critical thinking ability of class XI students of SMA Negeri 5 Surakarta on rotational dynamics subject and states that this ability still needs to be improved. This is supported by the critical thinking indicators, i.e.: decision making and inferencing, which are in the moderate category. Furthermore, for indicators of solving various problems and strategies for solving various problems fall into the low category. In addition, specifically on rotational dynamics material, the critical thinking ability of students at the high school level in general is in the low category. This is because the main ability in the critical thinking aspect, namely analyzing is still low (Dwyer et al., 2014; Putranta & Kuswanto, 2018).

Critical thinking skills can be improved by applying learning models that make students more active during the learning process in the classroom. In addition, students' critical thinking skills can also be improved along with the ability to collaborate (Styron, 2014). This is due to various collaboration competencies, e.g.: exchanging ideas in small groups will stimulate students to think critically in solving problems in the physics learning process. The critical thinking can arise through scientific experimentation activities to build and find facts that support arguments in the collaboration process (Hunaidah et al., 2018). However, collaboration skills in science learning still need to be improved (Sturner et al., 2021). One factor that makes collaboration skills need to be improved is that students still solve problems individually even though the learning process has been arranged in groups (Ilma et al., 2021). Collaborative activities in science learning, e.g.: decision making in formulating problems, making hypotheses, and making decisions do not appear in the learning process because students focus on worksheets alone (Pang et al., 2018). Collaboration skills can be improved through science learning with scientific activities such as practicum or experiments (Miller, 2016). This can be optimized through collaborative and cooperative learnings (Ilma et al., 2021). This ability is expected to be fostered in the science learning process, especially physics subjects on rotational dynamics.

The Science, Technology, Engineering, and Mathematics - Sports (STEM-S) learning approach is a new innovation and developed from existing STEM learning approaches. The STEM learning approach can teach two or more STEM subjects related to holistic and comprehensive learning activities that can optimize students' critical thinking skills (Abdurrahman et al., 2019). Learning in STEM education classes is more student-centered, involving students in organized discussion activities by forming study groups, and conducting simple experiments so that it can help foster collaboration skills (Thibaut et al., 2018).

Previous research in physics learning that uses the STEM approach, e.g.: Waluyo and Wahyuni (2021) who developed static fluid subject; Winarti et al. (2021), which examined STEM in physics learning for students' critical thinking skills; and Yulianti and Anjani's research (2019), which implemented STEM on momentum and impulse subject to develop collaboration skills. The addition of sports in the STEM approach is done to help contextualize the phenomena that can be studied using physics. Physics can be applied on various types of sports such as karate, softball, and athletics (Zumerchik, 1997). The additional component in the form of sports in this study is carried out on the physics subject of rotational dynamics. The STEM-S learning approach on rotational dynamics subject can be optimized by adding two elements, i.e.: augmented reality (AR) and local wisdom of *pencak silat* so as to make physics learning more contextual (Utami et al., 2017). Contextualized physics learning helps students to know the benefits of physics for everyday life (Neslihan, 2014). This can support the development of students' critical thinking skills and students' interest in actively collaborating in the learning process (Puspita et al., 2017; Desnita et al., 2021).

Pencak silat is a form of martial art originated from Indonesian society and belongs to the culture of the Malay community. The culture that underlies the *pencak silat* is known as *paguyuban*. *Paguyuban* is a culture of mutual cooperation, kinship, togetherness, solidarity, harmony, and social tolerance. *Pencak silat* as part of Indonesia's local wisdom has life values, viz.: being responsible for oneself, family, community, country, and God Almighty. Another value is noble character as a source of noble human attitudes, behavior, and actions needed to realize the ideals of religion and community morals (Kriswanto, 2015).

The description of the STEM-S elements in this study can be given as follows. The science element is the concept of rotational dynamics in *pencak silat* movements; the technology element is the use of AR to identify physical quantities in *pencak silat* movements; the engineering element is the design of *pencak silat* movement modifications produced by students; the mathematics element is the rotational dynamics equations; and the sports element is derived from various *pencak silat* movements studied in the learning process. This interesting collaboration in physics learning is expected to help improve students' critical thinking and collaboration skills needed in the 21st century.

The application of the STEM-S approach to improve critical thinking and collaboration skills requires supporting learning instruments. Learning intruments are tools used in the learning process to focus on the process (Prasetyo, 2013; Loughran, 2013). Learning instruments play a role to facilitate the implementation of the learning process (Shindharatna, 2018). One of these learning intruments is the student worksheet.

The student worksheets are defined as educational materials printed in the form of a sheet of paper that contains documents that summarizes and directs students to complete tasks and mentions the basic skills to be acquired (Prastowo, 2014). The student worksheet used in this study is made as instructions and also learning media.

METHOD

The research design used was quasi-experimental design with pretest-posttest control group design approach. Determination of experimental and control classes used in this study was done by simple random sampling. The description of the test design can be seen in Table 1. The control variables in this study include the teachers, materials, and initial learning steps (explanation of the subject material from the teacher). The dependent variables were critical thinking skills and collaboration.

Table 1. The test design.

Class Research	Initial Assessment	Final Assessment	Model	Learning Instruments
XI MIPA 1 & 3 (Experiment 1)	Pretest	Posttest	STEM-S	AR-assisted *pencak silat* student worksheet
XI MIPA 2 (Experiment 2)			Guided Inquiry	guided inquiry student worksheet
XI MIPA 4 (Control)			Think Pair Share	mind mapping student worksheet

This research was conducted in the Province of Yogyakarta Special Region, Indonesia with the research subjects being students from SMA Negeri 4 Yogyakarta. The classes used amounted to three XI MIPA classes consisting of two experimental classes and one control class. The experimental class 1 consisted of 44 participants, experimental class 2 consisted of 31 participants, and the control class consisted of 32 participants.

Observations were made to determine the suitability of the learning process with the syntax of lesson plans and student discussion activities. For the observation activities, the implementation of the lesson plan involved three observers, while for the discussion activities involved six observers. The observers made observations to assess the sustainability of students.

The distribution of assessment questionnaires between friends was carried out to obtain assessments on the aspects of collaboration ability. This assessment was carried out by each member for other members in a team. The distribution of this questionnaire was carried out twice at the end of each discussion activity. Moreover, the dissemination of questions was carried out to determine the improvement of students' critical thinking skills after the learning process. The questions were divided into pretest and posttest.

The data analysis techniques used in the effectiveness tests can be given as follows. The peer assessment questionnaire developed in this study used a Likert scale of 4. Likert scale was included in the ordinal scale group. This caused the need to transform the data from ordinal to interval scales. This transformation process was carried out using the method of successive interval (MSI) through Microsoft Excel (MS Excel) and an additional installation for the add ins feature on MS Excel.

Assumption tests were needed to be carried out as a condition for Manova's two-way statistical test. The assumption tests carried out were the normality and homogeneity tests. The normality test was performed on the data that had been transformed from a ratio scale to an interval scale. The normality test used was Shapiro-Wilk because the number of respondents was less than 200 respondents. The rule for deciding whether the data was normally distributed was to look at the significance (Sig.) or p value or probability value. If the value of Sig. > 0.05 then the data can be categorized as normally distributed. The homogeneity test was determined by considering the output result in the Box's text of equality of covariance matrices. If the Box's test produced a significance value above 0.05, it can be said that there was a similarity in covariance values between variables in terms of the comparison variable.

The One-Way Manova test was conducted in this study because the study consisted of one independent variable with three categories and two dependent variables, namely the ability to think critically and collaborate. The output results that had been analyzed were descriptive statistics, mulivariate, Levene's, between subject effect, post hoc, and partial eta squared tests. The descriptive statistics present the data with descriptive statistical analysis, e.g.: the average value for each existing group. The multivariate test showed the results of whether a class had an influence on critical thinking skills and collaboration simultaneously. If the resulting significance value was less than 0.05 then the null hypothesis will be rejected. The hypotheses proposed in this test include: i) there is no class influence on critical thinking and collaboration skills simultaneously (H_0), and ii) there is an influence of a class on critical thinking and collaboration skills simultaneously (H_1). The Levene's test provided homogeneity results more specifically for each variable. This test needed to be done to determine the test used in the *post hoc* test. If the resulting significance value was smaller than 0.05 then the data was not homogeneous and the interpretation of the data used the Games-Howell test, while if the resulting significance value was greater than 0.05 then the homogeneous data and interpretation of the data used the Bonferroni test. The test of between subject effect displayed the results of whether there was a class influence on critical thinking and collaboration skills for each variable one by one. If the resulting significance value was less than 0.05, there was no significant effect on the variable. The post hoc test showed the difference, in which classes were significant or not. This can be obtained if the resulting significance value was less than 0.05, which indicated that there is no significant difference between the classes. The interpretation of the partial eta squared value gave the following influences: 1) $\eta^2 = 0.01$ (small); 2) $\eta^2 = 0.06$ (moderate); and 3) $\eta^2 = 0.14$ (large) (Miles & Shevlin, 2001).

RESULTS

The normality test is carried out on data that have been transformed. As the number of respondents in this study is less than 200 respondents, the Shapiro Wilk data normality test is used. The rule for determining whether the data is normally distributed or not is to look at the Sig. value. If the Sig. value > 0.05 then the data can be categorized as normally distributed. The normality test result is given in Table 2. Based on Table 2, the result of the normality test for all categories show the values above 0.05. This means that the data are normally distributed.

The homogeneity test can be determined by looking at the output result on the Box's test of equality of covariance matrices. If the Box's test produces a significance value above 0.05, it can be said that there is a similarity in the covariance value between variables in terms of the comparison variable. The homogeneity test result is given in Table 3. Based on Table 3, it can be seen that the Sig. value is above 0.05, so that the data is said to be homogeneous. Hence, it can be concluded that the data satisfy the requirements of normality and homogeneity. Therefore, the one-way Manova can be conducted.

Table 2. Normality test result.

	Class	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Pretest of Critical Thinking	Experimental 1	.097	44	.200*	.960	44	.132
	Experimental 2	.119	31	.200*	.941	31	.086
	Control	.163	32	.031	.938	32	.064
Posttest of Critical Thinking	Experimental 1	.135	44	.042	.955	44	.087
	Experimental 2	.129	31	.200*	.946	31	.117
	Control	.109	32	.200*	.943	32	.090
First Meeting_Collaboration	Experimental 1	.109	44	.200*	.957	44	.101
	Experimental 2	.181	31	.011	.933	31	.054
	Control	.152	32	.057	.947	32	.120
Second Meeting_Collaboration	Experimental 1	.109	44	.200*	.956	44	.089
	Experimental 2	.129	31	.200*	.956	31	.223
	Control	.112	32	.200*	.952	32	.163

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table 3. Box's test result.

Box's M	22.728
F	1.071
Sig.	.373

The descriptive statistics analysis results are given in Table 4. Table 4 shows that the average value generated for the critical thinking ability variable in the experimental 1, experimental 2, and control classes are different in results for the pretest and posttest. The values are almost the same for the pretest between experimental class 1, experimental 2, and control classes, which ranges from 37.47 to 40.44. On the other hand, the values for experimental 1, experimental 2, and control classes are different, i.e.: 65.08, 55.09, and 51.62, respectively.

The results for the collaboration ability at the first and second meetings give approximately the same results with a range of 2.68 - 2.80 and 2.81 - 3.07. Even so, the experimental 1 class gives the highest result and there is an increase in the second meeting compared to the first meeting. To see whether the difference is specific or not, this test is continued by looking at the multivariate test output given in Table 5. Based on the output results from Table 5, it is known that the Sig. value for all types is 0.000 < 0.005. This indicates that there is a significant influence, which means that there is an effect of the classes on critical thinking skills and collaboration simultaneously.

Table 4. Descriptive statistics results.

	Class	Mean	Std. Deviation	N
Pretest of Critical Thinking	Experimental 1	40.44	9.267	44
	Experimental 2	39,90	9,603	31
	Control	37.47	13.179	32
	Total	**39.40**	**10.648**	**107**
Posttest of Critical Thinking	Experimental 1	65.08	9.206	44
	Experimental 2	55.09	11.865	31
	Control	51.62	12.962	32
	Total	**58.16**	**12.604**	**107**
First Meeting of Collaboration	Experimental 1	2.80000	.722113	44
	Experimental 2	2.67823	.707981	31
	Control	2.75734	.734603	32
	Total	**2.75196**	**.716775**	**107**
Second Meeting of Collaboration	Experimental 1	3.07241	.758137	44
	Experimental 2	2.81219	.779628	31
	Control	2.93400	.723874	32
	Total	**2.95563**	**.755148**	**107**

Table 5. Multivariate test results.

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Class	Pillai's Trace	.313	4.740	8.000	204.000	.000	.157
	Wilks' Lambda	.691	5.133[b]	8.000	202.000	.000	.169
	Hotelling's Trace	.442	5.524	8.000	200.000	.000	.181
	Roy's Largest Root	.428	10.915[c]	4.000	102.000	.000	.300

The Levene's test results in Table 6 show that the Sig. value for all variables is at a value larger than 0.05 except the critical thinking pretest, which has a value less than 0.05. This causes the variable to fall into the non-homogeneous category, while the other variables fall into the homogeneous category. In the post hoc test, data interpretation for critical thinking pretest is done with the Games-Howell test, while other variables are done via Bonferroni test.

Table 6. Levene's test result.

Variable	Levene's Statistics	df_1	df_2	Sig.
Pretest of critical thinking	5.675	2	104	.005
Posttest of critical thinking	1.788	2	104	.172
First meeting of collaboration	.601	2	104	.550
Second meeting of collaboration	.038	2	104	.963

Table 7. Test of between subject effect results.

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Class	Pretest of Critical Thinking	174.734	2	87.367	.767	.467	.015
	Posttetst of Critical Thinking	3763.948	2	1881.974	14.968	.000	.224
	First Meeting of Collaboration	.271	2	.136	.260	.771	.005
	Second Meeting of Collaboration	1.253	2	.626	1.101	.337	.021

a. R Squared = .015 (Adjusted R Squared = -.004); b. R Squared = .224 (Adjusted R Squared = .209); c. R Squared = .005 (Adjusted R Squared = -.014); and d. R Squared = .021 (Adjusted R Squared = .002)

The test of between subject effect results from Table 7 show that all variables have a value of Sig. > 0.05, except for the critical thinking posttest. This causes the results to have a significant effect only on the critical thinking posttest. This means that there is a significant influence of the classes on the critical thinking posttest.

Table 8 shows the results for the critical thinking posttest variable. This is because the variable has a significant difference in the results of the previous test. This variable is reviewed using the Bonferroni test based on the previous test that has been done. Based on the results in Table 8, the difference in critical thinking posttest occurs between experimental 1 with experimental 2 classes and experimental 1 with the control classes. This can be seen from the resulting Sig. value of 0.001 < 0.005 and 0.000 < 0.005.

Table 8. The post hoc test result.

Dependent Variable		(I) Kelas	(J) Kelas	Mean Difference (I-J)	Std. Error	Sig.
Posttest of critical thinking	Bonferroni	Experimental 1	Experimental 2	9.99*	2.629	.001
			Control	13.45*	2.605	.000
		Experimental 2	Experimental 1	-9.99*	2.629	.001
			Control	3.46	2.826	.670
		Control	Experimental 1	-13.45*	2.605	.000
			Experimental 2	-3.46	2.826	.670
	Games-Howell	Experimental 1	Experimental 2	9.99*	2.543	.001
			Control	13.45*	2.679	.000
		Experimental 2	Experimental 1	-9.99*	2.543	.001
			Control	3.46	3.129	.514
		Control	Experimental 1	-13.45*	2.679	.000
			Experimental 2	-3.46	3.129	.514

Based on observed means. The error term is Mean Square (Error) = .569.
*. The mean difference is significant at the .05 level.

Discussion

The effect of the product developed in this study on critical thinking skills can be seen in the Manova test results (See Table 5). These results show that there is a significant effect of the classes on critical thinking skills. Specifically, the results show that the influence is on the results of the critical thinking ability post-test with differences in the critical thinking post-test occurring between experimental 1 with experimental 2 classes and experimental 1 with the control classes. Based on the value of the partial eta squared, the contribution of the class gives an effect of 0.157, which is in the category of large contribution because it is larger than 0.14 (Miles & Shevlin, 2001).

Critical thinking skills can increase in this study due to various aspects in the lesson plan, student worksheet, and assessment instruments. The first aspect is the lesson plan that describes the process of learning. There are various reasons that make students able to explore the critical thinking process, including trying to find out and care more about the physics material they learn because at the beginning of learning, the importance of rotational dynamics material has been laid out in solving problems that occurs in everyday life (Ardianti et al., 2020).

The role of the assessment instrument product is through the presentation of various contextualized problems that make students need to think critically to solve the problems presented (Neslihan, 2014). In addition, each problem presented requires a process to achieve the result. This can be used to see and assess the critical thinking process.

The main role of various instruments to improve critical thinking skills lies in the student worksheet that integrates the learning process with the STEM-S. This process can be seen as follows. In section I, the introduction of the student worksheet presents a popular article entitled "Physics behind *pencak silat*". This article is presented as a trigger for students to start releasing curiosity. At the end of the article, students are asked to formulate questions based on the article they have read. In part II, the investigation, students are asked to explore the various quantities of rotational dynamics, namely torque, moment of inertia, and angular momentum that exist in the *pencak silat* movement. This exploration is carried out through AR technology that displays the *pencak silat* artist directly, which is then analyzed using the Tracker software. The use of AR to display *pencak silat* movements obtains positive responses from students, e.g.:

> "Wow, the guy is really cool, the *pencak silat* comes out of the cellphone"- (**students**)

There are various physical quantities presented in the Tracker analysis, e.g.: time, speed, acceleration, angular velocity, and angular acceleration. In this exploration process, there are several aspects that show the critical thinking process based on observations. When students analyze the motion Tracker in AR, they will give each other opinions about the units displayed and then try to find out the definition of each unit by searching the internet or searching in books. The conversation is as follows:

Student 1: What is the connection of speed with acceleration?
Student 2: Speed is the change in distance per time, while acceleration is the change in speed per time.
Student 1: But how come this is the case? And what is its connection with torque?
Student 2: Now that makes me confused too.
Student 3: Let me look again first. Oh, this torque formula has force in it. If we break it, it means there is acceleration.

Student 4: Oh yes that, that means we input that.
Student 1: But is this acceleration correct when we input it?

In the discussion process, various questions will continue to roll until finally they can answer the questions. This shows that there is a process for deciding whether a claim is true, almost true, partially true, or false, which is part of critical thinking (Girod, 2015). In the process of deciding there are also aspects that are contradictory or need to be considered so as to trigger the critical thinking process (Febriani et al., 2023).

In addition to the exploration process, students are also asked to try to do some *pencak silat* movements and match them with the results of calculations and theory. This can help in the ability to identify relationships, analyze probabilities, make predictions and logical decisions from a variety of different facts. All of these abilities help improve critical thinking skills (Halpern, 2014). The process can be illustrated as follows:

Student 1: How about it, is there no perceived difference from those three movements?
Student 2: I feel like their the same.
Student 1: I feel different, it's easier to punch straight.
Student 2: Why? I still think is just the same.
Student 3: I think it should be different, because the calculation of the torque value is different.

In connection with the use of the STEM-S, various questions related to producing instruments in the form of *pencak silat* movement designs are given as follows: 1) the best movement criteria can be met with the conditions of what kind of rotational dynamics? And 2) how to demonstrate and design new motion or modify the ones you have learned based on the physics concepts of rotational dynamics? The result obtained is that the entire team makes movements based on the results of the previous theory in various ways, such as: sending videos, photos per step, and also drawing the movement directly on the student worksheet. This process can develop meaningful learning through holistic and comprehensive integrated systems and knowledge, concepts, and skills that can optimize students' critical thinking skills (Abdurrahman et al., 2019; Pertiwi et al., 2019).

The effect of the instruments developed in this study on collaboration ability can be seen from the results of observational descriptive tests (see Table 4) and Manova tests from peer assessments (see Table 5). Based on the results of quantitative descriptive tests at the first meeting, all classes show more than 70% collaboration ability. This shows that all three classes influence collaboration skills. At the second meeting, there is an improvement in each class. However, the highest increase is found in experimental 1 class, from 73.5% to 81%. On the other hand, the lowest increase is found in experimental 2 class, from 71% to 74%. The latter result is not much different from the control class, which is increased from 71% to 75%. These results do not show the initial and final results but are the results of observations during the implementation of the collaboration process in two meetings.

Based on the results of the Manova test, there is a significant influence of the classes on critical thinking and collaboration skills. However, a more specific results show that there is no significant difference in the collaboration ability. This can be caused because the Manova data inputted are the assessment data between peers after the treatment. Even so, this result also shows an increase from the first meeting to the second meeting descriptively.

In addition to the quantitative descriptive tests, there are also qualitative descriptive results obtained based on observations. It is obtained that there are contributions of various instruments that have been developed to the collaboration ability. The lesson plan and student worksheet are the main instruments that trigger the emergence of collaboration ability in the learning process. The description of the learning process in the lesson plan is that students are formed into groups in order to be able to collaborate. Learning becomes student-centered, engages students in organized discussion activities by forming study groups, and conducts simple experiments, encouraging students to take responsibility for their work so that they can understand the learning material, building knowledge while learning through shared experiences rather than individual experiences (Thibaut, et al., 2018).

In the student worksheet section, students discuss various problems presented. At this stage, students start with various key points that show collaboration and also divide tasks in groups. The keywords include: "come here do it"; "Is this, right?"; "Yes"; "Uh, that is not it"; "We divide the task so that someone writes and someone else makes a question". In addition, there are several task divisions, e.g.: a student in charge of installing the needed applications, a student to scan markers, a student to do calculations, and two students demonstrating *pencak silat* movements. Moreover, students also look excited and curious to complete the student worksheet by working outside the classroom to concentrate more and be able to demonstrate *pencak silat* movements freely.

In relation to the use of the STEM-S, students are required to learn and collaborate with other students. This causes students to work together to complete projects and get help from more experienced students (Sahin, 2015). The visible indicators of this process are working effectively in groups, contributing to making agreements for common goals, and being responsible in groups. This is in accordance with collaboration indicators by Yulianti & Anjani (2019).

CONCLUSION

The *pencak silat*-based STEM-S learning instruments developed in this study are effective for improving critical thinking and collaboration skills of senior high school students in physics subject, especially rotational dynamics. This effectiveness is based on: 1) descriptive analysis of the results of observation of collaboration skills that are in the effective category, 2) multivariate tests that provide the results of the influence of classes on the ability to think critically and collaboration simultaneously, and 3) in the multivariate follow-up test the critical thinking posttest variable has a significant influence and occurs between experimental 1 with experimental 2 classes and experimental 1 with the control classes.

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