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The effect of epistemological understanding of physics on students' critical thinking skills

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Abstract

The work aimed to designate the level of the epistemological understanding of physics, the student’s critical thinking skills and to analyse the direct effect of the epistemological understanding of physics on students' critical thinking skills. This research is ex-post-facto research. The samples were 61 final year students. The instrument used for the epistemological understanding of physics adopts the instrument form of the epistemological understanding assessment and standardised epistemological understanding assessment. The instruments used have been validated theoretically and empirically. Data were processed with SPSS V22.0 and Analysis of Moment Structure (AMOS) V24.0 software. The results show that students’ understanding of physics epistemological and critical thinking skills are in the medium category. The students' understanding of physics epistemology has a positive and significant effect on critical thinking skills. These findings can be used to develop appropriate physics learning resources.

Keywords: AMOS V22.0, critical thinking, epistemological understanding, ex-post-facto, learning, physics

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1. Introduction

1.1. Theoretical framework

Epistemology is a branch of philosophy which is associated with science and belief. In the context of science, epistemology is concerned with the nature of science and scientific knowledge by posing problems such as (1) how students know 'what they know', (2) how to create new knowledge, (3) how to reach conclusions and (4) what constitutes reasonableness. Students' learning styles, how they learn and how much time they spend constructing their knowledge and understanding are all influenced by their beliefs, attitudes and epistemological understandings. In terms of epistemology, Kuhn et al. (2000) found that there is an intrinsic intellectual value that plays a significant role in retaining motivation in adulthood. Epistemological understanding is the term for this intellectual value, such that someone with a sound epistemological understanding has an innate motivation that lasts into adulthood. This will be extremely beneficial in promoting life-long education.

Epistemological understanding has a dimension that is influenced by the content of a particular field, where a research result that also employs the construct of epistemological understanding turns out to make a difference, depending on the level of formal education received (Baxter, 2004; Bråten & Strømsø, 2004). The physical world appears to have a special component in epistemological knowledge, making it further clearer that a person's epistemological understanding can be specialized with the involvement of a particular profession. The researcher will observe an epistemological understanding of physics in this example.

The importance of this need must always be reflected in educational standards. With the quick interchange of knowledge, critical thinking abilities are becoming increasingly important in modern civilization. To criticize and evaluate certain items, critical thinking is a mental activity accompanied by a process and technique that employs reason, insight, awareness, imagination and sensitivity (Mainali & Bhawani, 2011). Critical thinking serves as a technique for analyzing and evaluating information (Arafah et al., 2020; Arafah, Amin et al., 2021; Arafah, Helmi et al., 2021; Basham et al., 2013). The main characteristics of the 21st century are marked by the development and use of information and communication technologies in almost all areas of life, one of which is in the teaching and learning process. One of the most important demands of the world of work in this century is critical thinking skills. So it takes intellectual values to optimize critical thinking skills.

Educational researchers address the conceptual and operational definitions of epistemological beliefs in different ways. Schommer (1990) characterized epistemological beliefs as systems made up of nearly independent dimensions of 'knowledge' and 'knowing', including knowledge in the disciplines of physics. Various studies have shown that the main expectations of students in physics are derived from attitudes, beliefs and assumptions about physics. This will later provide direction for their future learning (Hammer & Elby, 2003; May & Etkina, 2002).

This emphasizes how important an epistemological understanding of physics is for a student. Regarding the skills needs of students, general skills are intended for every graduate of higher education, including undergraduate programs. The Ministerial Regulation in Indonesia explains in the first point that among the skills in question are being able to apply logical, critical, systematic and innovative thinking; and the fifth point explains that university graduates must be able to make appropriate decisions when solving problems in their area of expertise, based on the results of information and data analysis. This explanation emphasizes how important critical thinking skills are for undergraduate students. Critical thinking is defined as the ability to interpret, analyze, evaluate, infer, explain and self-regulate (Bailin et al., 1999). Critical thinking skills must be developed for students to be competitive in the 21st century and to be involved in solving basic epistemological problems {Arafah, 2021; Hammer, 2000; Kuhn & Park, 2005; Żyluk et al., 2018).

Review articles by Hofer (2001, 2004) summarise the different lines of research on the topic of the importance of epistemological understanding and look for congruence between these articles. The main developmental function that determines the maturity of epistemological understanding is none other than the coordination between the subjective and objective dimensions of knowledge (in this study, physics) (Barzilai & Chinn, 2018; Barzilai & Weinstock, 2015; Żyluk et al., 2016). Through a radical shift, the subjective dimension that initially dominates will gradually be abandoned, until finally the two are coordinated and reach an equilibrium where no one beats each other (Kuhn et al., 2000).

The increase in epistemological understanding of physics (EUoP) is presented in levels described in Table 1. A person at the absolute level (as well as a realist) considers knowledge as an objective entity located in the outside world and can be known with certainty. A person in the multiplist category (described in Table 1) places the source of knowledge from ‘known objects’ to ‘known subjects’, so that it becomes the basis for the uncertain nature or the subjective nature of knowledge. An evaluativist reintegrates the objective dimension of ‘knowing’, acknowledging the existence of uncertainty without ignoring evaluation. Thus, two people with opposing opinions can have the same position or both can be ‘right’. One of the two can have a higher truth than the other (or ‘more correct’), as long as it is supported by a stronger argument.

Table 1
Level of Development of Epistemological Understanding

Level	Claims	Reality	Knowledge	Critical thinking
Realist	Claims are copies of external reality	Reality can be known directly	Knowledge is sourced externally and is definite	Critical thinking is not required
Absolutist	Claims are facts that are true or false in their representation of reality (possibly false beliefs)	Reality can be known directly	Knowledge comes from external sources and is definite	Critical thinking is a means to compare claims with reality and determine whether they are true or false
Multiplist	Claims are opinions freely chosen by and responsible only to their owners	Reality cannot be known directly	Knowledge comes from external sources and is definite	Critical thinking is considered irrelevant
Evaluativist	Claims are judgments that can be evaluated and compared according to the criteria of argument and evidence	Reality cannot be known directly	Knowledge is shaped by the human mind and is uncertain	Critical thinking is valued as a means to encourage reasonable claims and increase understanding

Another study (Kuhn et al., 2000) compared epistemological thinking in terms of personal taste judgments (e.g., acidity), aesthetic judgments (e.g., whether a work of art is better than another), ethical judgments (e.g., whether stealing is wrong), truth judgments in the social world (e.g., how an energy generator is financed) and truth judgments in the physical world (e.g., how the shape and motion of an electron).

Epistemological understanding also has dimensions that are influenced by the content of a particular discipline, where a research result that also uses the construct of this epistemological understanding will turn out to be different depending on the depth of formal education that has been passed (Baxter, 2004; Bråten & Strømsø, 2004). Moreover, epistemological understanding turns out to have a special dimension related to the physical world (to be explained later); this further makes it clear that one's epistemological understanding, in general, can be specialised with the involvement of a particular discipline. The strength of the existing literature is that it provides a complete description of the dimensions of epistemological understanding and indicators of critical thinking skills. However, it is not at all specific in embedding certain disciplines (especially physics). The available literature related to the epistemological understanding of physics is only a philosophical review of the epistemology of physics in education, but it is sufficient to give us an idea that there is indeed a vital role of epistemological understanding in teaching physics. In this case, the researcher will look at the EUoP.

1.2. Related research

In the nomenclature that we define, the word physics has a position as a material object, and the word epistemology has a position as a formal object. So the provision of measuring scales and instruments related to epistemological understanding, in general, will also apply to epistemological understanding for certain disciplines (Zyluk et al., 2016; Barzilai, 2015; Zyluk, 2016), including physics. The only difference is that the philosophical issues involved will be limited in the scope of university physics material (Bishop, 2011; DiSessa, 1993; Hammer, 1994; Stathopoulou, 2007). So, in this study, physics has a place as content in measuring EUoP.

Table 1 shows that critical thinking can only be done by students who have a good epistemological understanding. Critical thinking is rational and reasonable thinking that can be reflected on during decision-making (Ennis, 2015). Ennis (2015) emphasises the principles and skills of subject-neutral critical reasoning, i.e., logical principles that are not only limited to a specific discipline but also can be applied broadly. Ennis (2015) stated that there are 12 indicators of critical thinking skills that are summarized into 5 stages (Table 2).

Table 2

Critical Thinking Skills Indicators and Their Description

Stages	Critical thinking skills indicators involved
Basic clarification	This stage is divided into three indicators, namely formulating questions, analyzing arguments, and asking and answering questions.
The bases for the decision	This stage is divided into two indicators, namely assessing the credibility of the source of information and observing and assessing the report on the results of the observations.
Inference	This stage consists of three indicators making deductions and assessing deductions, making inductions and evaluating inductions, and evaluating.
Advanced clarification	This stage is divided into two indicators, namely defining and assessing definitions and identifying assumptions.
Supposition and integration	This stage is divided into two indicators, predicting and combining.

Based on this description, we can see the correlation between EUoP and critical thinking skills. An epistemological understanding of physics will greatly aid critical thinking skills. Strengthening critical thinking skills through the intervention of an epistemological understanding of physics can only be accomplished by overhauling the structure of the physics material to be taught, with an emphasis on the epistemological aspects of physics.

This is a long-studied topic, particularly in terms of critical thinking skills and epistemological understanding of physics. However, we can see that none of these studies digs deeper into a specific discipline, including physics. Physics is a subject that becomes more complex as it is studied, and adult learners always experience a lack of motivation when learning advanced physics. However, as educational research (particularly in educational technology) has advanced, the reconstruction of physics materials such as this has received little attention from educators and researchers. This situation is exacerbated further by the lack of a description of the epistemological understanding of physics for students, making it impossible to follow-up on the most appropriate learning method used in physics learning based on an epistemological understanding of physics. As a result, we need a basic understanding of how students understand epistemological physics and how this epistemological understanding of physics influences critical thinking skills.

These two skills have been extensively researched. Epistemological beliefs or epistemological understanding do not have direct implications for the continuity of learning. This is because this characteristic is not embedded in a specific scientific discipline.

1.3. Purpose of the study

The research aimed to designate the level of the epistemological understanding of physics, and the student's critical thinking skills. Additionally, this study investigates how the epistemological understanding of physics influences critical thinking skills as a form of confirmation that embedding physics disciplines in these attributes can have a positive effect on critical thinking skills. The research hypothesises that the physics epistemological understanding has a direct positive influence and is significant towards the critical thinking skills of the physics students of mathematics and natural sciences in Makassar State University.

2. Method and materials

2.1. Research model

This is a causal ex-post-facto study. The object under study is not treated in any way during the research process. This study will demonstrate the relationship between variables and test the hypotheses that have been developed. This study attempts to analyze the data using the model developed from the theoretical framework. Hypothesis testing used the structural equation modelling (SEM) analysis technique which is operated through the AMOS programme. SEM is a form of multivariate statistical technique and a combination of factor analysis and regression, where the aim is to test the relationship between variables from a previously built model (Hair et al., 2020).

2.2. Participants

The population in this research was all undergraduate physics education students who were in the final semester of the 2020/2021 academic year. Students consist of three classes with a total of 71 people. The sample of this research is some students of the physics education study programme. To obtain a representative sample, a sampling technique was used, namely proportionate stratified random sampling. The sample size used was determined through the Slovin formula (Ryan, 2013). Based on the Slovin formula, the number of samples from the total population is N = 96 and the error tolerance level is e = 5%, which is 61 students. This size is the minimum sample size, and to avoid the mortality factor (a situation that forces the sample size to decrease beyond the control of the researcher), the researchers took 64 students.

2.3 Data Collection Tools

The researcher developed the epistemological understanding of physics instruments, which have undergone theoretical and empirical validation. Personal taste judgment, aesthetic judgment, ethical judgment, social world truth and physical world truth were measured as a student's score in comparing two opposing views. Attributes of epistemological understanding of physics can be measured using the form of instruments adopted from the epistemological understanding assessment (EUA) and standardized epistemological understanding assessment (SEUA). These two assessment instruments are forms of instruments adopted by researchers in developing research instruments. In assessing whether the transition from the absolutist level to the multiplist level has occurred in students, then each pair of statements will be followed by the following questions: 'Can any of their views be correct or can both have the truth?' The diagnostic answer for the level of absolutist is 'One view is correct'. If the student answers 'Both can have the truth', then students will proceed to the following questions to see if there is a transition between the multiplist level and the evaluativist level: 'Can one view be better or more correct than the other?'

Can only one of their views be true, or can both have the truth?

a. Only one view is correct (score 1)
b. Both can have truth (choose one)

If both have the truth:
Can one view be better or more correct than the other?

a. One view is better than the other (score 3)
b. One view cannot be better than the other (choose one) (score 2)

Figure 1
Questions for assessing whether the transition from the absolutist level to the multiplist level has occurred in students

The response 'One view may not be more correct than the other' is the diagnostic response for the multiplist level, while 'One view may be more correct than the other' is the diagnostic response for the evaluativist level. Instructions for choosing an answer can be seen in Figure 1.

A student is labelled as an absolutist (A), multiplist (M) or evaluativist (E) in a particular scoring domain if the student answers two of the three statements in the same way in a particular domain. Each statement is followed by the same question in all domains of epistemological understanding. When students give different responses to the three questions, they will be given an M-level label for that domain. Based on the responses given by students in all domains, the student profile can be determined through the five-digit letters that indicate the level in each domain, for example, MAAEE, where each letter represents the level of epistemological understanding in the areas of personal taste, aesthetics, value judgments, judgments on the social world and judgments on the physical world. Each profile A will have a score of 1 point; M will have a score of 2 points and E will have a score of 3 points. Each area of the EUA is possible to score from 3 to 9 points; therefore, the maximum summary score for the entire question is 45. For SEUA, scores in the domain range from 5 to 15; for the overall score, participants can achieve a maximum score of 75 points. We then chose the SEUA scoring technique in this study.

2.3 Data collection process

The measurement of epistemological understanding of physics in this study adheres to the SEUA form and will continue to employ the dimensions of the objective and subjective sides of knowledge, as proposed by Kuhn et al (2000). Table 3 shows the indicators of epistemological understanding of physics derived from this. The aesthetic elements of physics are divided into simplicity, harmony, complexity, correspondence, unity, invariance, coherence and abstraction in the article 'Beautiful Physics: Re-vision of Aesthetic Features of Science through Literature Review' (Jho, 2018). The ethical issues raised are actual issues that are specifically discussed in the physics and ethics education project.

Table 3

Domains of Judgement in Measurement of Epistemological Understanding of Physics

Judgments domain	Descriptions
Judgments of personal taste	Assuming two opposing views on the issue of 'taste judgments within the scope of the study of physics' can have the truth, but one view has a higher level of truth.
Aesthetic judgements	Assuming two opposing views on the issue of 'aesthetic Judgements regarding the scope of the study of physics' can have the truth, but one view has a higher degree of truth.
Value judgements	Assuming two opposing views on the issue of 'value judgements of the scope of the study of physics' can have the truth, but one view has a higher level of truth.
Judgments of truth about the social world	Assuming two opposing views on the issue of 'judgments of the social world regarding the scope of the study of physics' can have the truth, one view has a higher degree of truth
Judgments of truth about the physical world	Assuming two opposing views on the issue of 'judgments of the physical world regarding the scope of the study of physics' may have some truth, one view has a higher degree of truth.

Determination of the level of epistemological understanding of physics for each respondent is carried out based on Table 4. This levelling was made by researchers through a modification of levelling developed by Żyluk (2016). The level determination made by the researcher is presented in Table 4.

Table 4
Category Determination of Epistemological Understanding Levels of Physics

Percentage	Level
$89 > x \geq 100$	E
$78 > x \geq 89$	E-
$67 > x \geq 78$	M+

56 > *x* ≥ 67	M
44 > *x* ≥ 56	M-
33 > *x* ≥ 44	A+
≤33	A

Table 4 is a benchmark in determining the EUoP level made by researchers by adopting a level transition as in SEUA. Researchers tried to make levelling easier by using a score percentage that was much more flexible and not limited by the number of pairs of items asked.

The researcher developed 50 test items for the epistemological understanding of physics. The instrument for understanding the epistemological physics of physics contains items that have guaranteed representations of each indicator. Based on the validator's findings, an internal consistency coefficient of 0.893 was calculated.

Each test item is stated to be theoretically valid, but only 40 items were used for empirical validation analysis due to optimal time estimation concerns. Empirical validation was accomplished by administering a trial test to 91 students from the Department of Physics. The obtained correlation coefficient values range from 0.532 to 0.877. It was found that from the 40 items, 37 items were valid. The instrument reliability test was carried out by calculating Cronbach's Alpha coefficient. The coefficient obtained is 0.808, which is in the very high category.

The indicators of students' critical thinking skills used in this study are interpretation, analysis, evaluation and inference. According to Facione and Gittens (2016), there are at least six skills involved in the critical thinking process. The skills in question are interpretation, analysis, evaluation, inference, explanation and self-regulation. However, only four indicators will be used considering the time constraints and the suitability of the physics material.

Based on the results of the validator's assessment of the critical thinking skills instrument, the internal consistency coefficient was 0.938. Thus, the internal consistency of the assessment results between validators is classified as strong relevance (very high). These results indicate that the instrument is adequate for further analysis. Empirical validation was carried out by giving a trial test to 81 students of the Department of Physics. It was found that every nine items developed were also empirically valid. The correlation coefficient values obtained were in the range of 0.458–0.790. The instrument reliability test was carried out by calculating Cronbach's alpha coefficient. The coefficient obtained is 0.825 and is in the very high category.

The requirements that must be met to perform inferential analysis using SEM are to go through normality test, linearity test and model testing. Based on the requirements test that has been carried out, it is found that the data has met the requirements for further analysis by SEM.

The normality test was carried out on each variable and all variables together (multivariate) using analysis from the AMOS 24 application output. A multivariate normality test was performed using AMOS 24 referring to the output of the assessment of normality. If the value of characteristic ratio (CR) at the output of the assessment of normality is between −2.58 and 2.58, then the data is said to be normally distributed. Based on the CR shown in the assessment of normality output, where the value obtained is still within the range. So it can be concluded that the data come from a population that is normally distributed.

In this study, the linearity test was assisted by SPSS 26 by looking at the F-value through the analysis of the variance table. Furthermore, by comparing the significant value (Sig.) with 0.05, the deviation from the linearity value of Sig. is obtained (>0.05). It can be concluded that there is a significant linear relationship between the epistemological understanding of physics and critical thinking skills.

2.5. Data analysis

In this study, the data analysis used SEM assisted by the statistical application of AMOS V24.0. SEM illustration with AMOS V24.0 distinguishes two variables based on their symbolising form. The ellipse represents the latent variable and the square represents the manifest variable. Latent variables are variables that cannot be measured directly but can only be manifested indirectly by manifest variables.

Factor analysis is a prerequisite test to perform multiple linear regression analysis. The goal is to identify the right model to explain the relationship between indicators and variables (Becker et al., 2012; Hair et al., 2012). This factor analysis is called confirmatory factor analysis (CFA). Testing a model with the AMOS V24.0 application is carried out by considering the goodness of fit (GoF). The criteria for this judgement can be seen in Table 5. If a model does not meet the GFI criteria, it can be done with modification indices. This feature is an option given by AMOS to reduce the chi-squared value so that the index matches the criteria.

Table 5

GoF Criteria

Index	Cut-off value
Chi-square	~ 0
CMIN/df	≤2.00
GFI	>0.90
AGFI	>0.90
TLI	>0.90
CFI	>0.90
RMSEA	*≤0.08*

3. Results

The results of determining the level of epistemological understanding of physics for students of the physics education study programme can be seen in Table 6.

Table 6.

Determining the level of EU of Physics for Students of the Physics Study Program

Indicators	Level
Judgments of personal taste	M+
Aesthetic judgements	M
Value judgements	M−
Judgments of truth about the social world	M−
Judgments of truth about the physical world	M-
Profile	M+ M M− M− M−

Table 6 shows that the profile of the epistemological understanding level of physics education students is M+M M− M− M−. In other words, the level for the personal taste domain is multiplist with evaluativist tendencies; the level for the aesthetic domain is multiplist; the level for the domain of ethics/values, social truth and physical truth is multiplist with absolutist tendencies.

The results of the measurement of the epistemological understanding of physics students majoring in physics gave a level of M+ M M− M− M−, which described the levels for the dimensions of personal taste, aesthetics, ethics/values, the truth of the social world and the truth of the physical world, respectively. These results follow the characteristics of each dimension, described by Żyluk et al. (2016), that epistemological understanding should develop following these sequences and result in a higher level for the dimension of personal taste, followed by the dimensions of aesthetics, ethics/values, the truth of the social world and the truth of the physical world. Here we can conclude that the level of students majoring in physics for the domain of personal taste is multiplist with evaluativist tendencies; the level for the aesthetic domain is multiplist; the level for the domain of ethics/values, social truth and physical truth is multiplist with absolutist tendencies.

The location of the order of the dimensions of the truth of the physical world which is in the last position in its development has given us an idea of the importance of understanding personal tastes, aesthetics, ethics/values and social truths in learning physics. As physicists and future physicists, the philosophical aspects mentioned above must be integrated into every college physics lesson, especially in the physics department.

Based on the results of factor analysis using AMOS 24, the results of the analysis are shown in Figure 2.

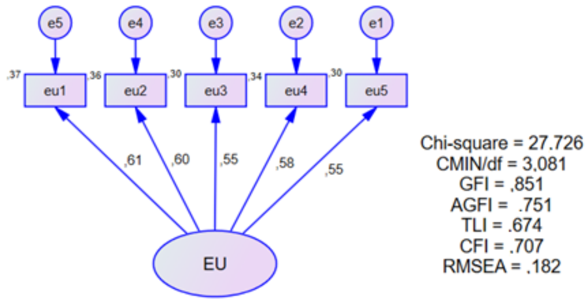

Figure 2

CFA Model

An indicator that has a high loading factor means that it has a high contribution to explaining the latent construct. A loading factor with a magnitude of 0.50 or more than the indicator is considered to have strong validation in explaining the construct (Hair et al., 2010). The variance extracted from physics epistemological understanding variables is 0.355. The results of the variance extracted from the physics epistemological understanding variable are below 0.500, which means that there is no convergence to explain the existing constructs.

It is necessary to test the structural model to find out the theoretical model of the relationship between variables and indicators which is confirmed by the facts shown by empirical data. The suitability of the theoretical model with empirical data is presented through GoF statistics. The initial model can be seen in Figure 3.

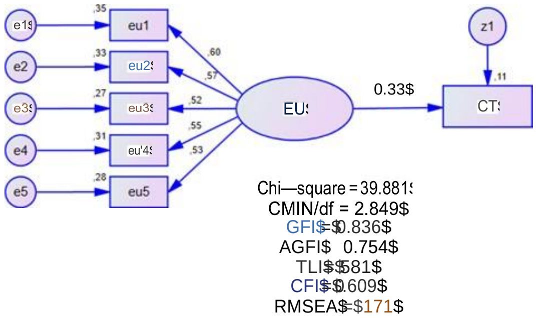

Figure 3

Initial SEM

EU stands for epistemological understanding and CT stands for critical thinking. The eu1, eu2, eu3, eu4 and eu5 are, respectively, the EU indicators for judgment of personal taste, aesthetic judgment, ethical judgment, the judgment of the truth of the social world and judgment of the truth of the physical world.

Based on the initial analysis of variables in Figure 3 the results of the overall fit index are shown in Table 7.

Table 7

Results of the Initial SEM

Index	Value	Critical value	Evaluation of model
Chi-square	39.882	~ 0	
CMIN/df	2.849	≤2.00	
GFI	0.836	≥0.90	
AGFI	0.754	≥0.90	Not fit
RMSEA	0.171	≤0.08	
TLI	0.581	≥0.90	
CFI	0.609	≥0.90	

Table 7 shows that no index meets the cut-off value (fit) while the other six are still not fit. To increase the overall fit index, modifications were made using the modification indices provided by AMOS V24.0. This modification aims to reduce the chi-squared value to the maximum. Suggestions for modification indices of the output of AMOS V24.0 can be seen in Table 8.

Table 8

Modification Indices from AMOS 24

	M.I.	Par change
e3 <-> e2	20.869	5.193

The results of the modification indices in Table 8 are recommendations from AMOS 24 regarding the variables or errors that must be further processed for modification. Modifications are made through several relationships between error variables that have a large chi-square change value. The modification results were then re-analyzed with the results shown in Figure 4.

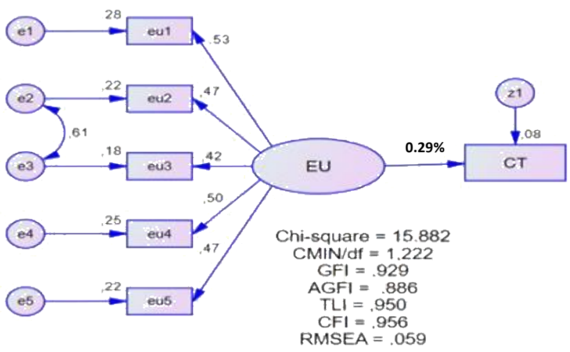

Figure 4

Final SEM Model

The results of the SEM model shown in Table 10 have met the criteria, and so this model can be accepted. Based on the final analysis of variables shown in Figure 4, the results of the overall fit index are shown in Table 9.

Table 9

Results of the Final SEM

Index	Value	Critical value	Evaluation of model
Chi-square	15.882	~0	
CMIN/df	1.222	≤2.00	
GFI	0.929	≥0.90	
AGFI	0.886	≤0.90	Fit
RMSEA	0.059	≤0.08	
TLI	0.950	≥0.90	
CFI	0.956	≥0.90	

After modifications, a final model with a fulfilled overall fit index is obtained (Figure 4). This final model is then defined as a structural model to explain the effect of epistemological understanding of physics on critical thinking skills. The linear regression equation is formed from the value of the regression weight. The structural equation of the regression analysis is based on the final overall fit model, which can be mathematically written:

$$Y=0{,}29X+ \varepsilon$$

where X is the physics epistemological understanding and Y is the critical thinking skill.

It has previously been hypothesized that epistemological understanding of physics has a positive effect on critical thinking skills. Such findings can also be found in the results of data analysis. These findings suggest that there is a close relationship between epistemological and critical thinking. We explained in the theoretical framework that critical thinking, specifically argumentative reasoning (as evoked by the developed instrument), will intersect with an individual's concept of the nature of knowledge (i.e., epistemological thought).

4. Discussion

This study considered the appropriate developmental stage. This is why the population is restricted to students in their final semester. The central tenet of epistemological development research is that it is always concerned with its ideas about the nature of knowledge. These students' characteristics will change as they grow and progress through college. This stage of development is covered in the study of philosophy related to the nature of knowledge, but it is never covered in informal education studies' courses.

The developed instrument necessitates assessing the strengths and weaknesses of ideas as items of knowledge as well as estimating the level of epistemological thinking. It can also provide insight into the relationship with information literacy, as to be fully informed, one must be able to make a reasonable assessment of the quality of sources, such as what is contained in the instrument. For this attribute to be measured, epistemological reflection is required. Although we did not specifically link epistemological understanding with metacognitive skills (i.e., students' ability to think and organise their thinking processes) in this study, we already know that this type of thinking is the foundation for critical thinking, where thorough and unbiased thinking is required, and all of this can only be controlled consciously if one has good metacognitive skills. According to various studies, the level of development of epistemological thinking and metacognition will go hand in hand as a person grows up, but the development of both can only be obtained optimally with appropriate treatment and support. Of course, the question support should come from the lecture learning process.

A proven hypothesis in this study is that epistemological understanding of physics has a positive effect on critical thinking skills. This is also evident when one investigates various theoretical studies and other unrelated research findings. Students will always need to be familiar with ambiguity and uncertainty, as well as be willing to change their minds radically if new evidence undermines theories that they previously believed to be true or can support theories that they are unfamiliar with.

In general, final semester physics majors have only a multiplist level epistemological understanding of physics. Only a small percentage of people are evaluativists. This is in accordance with the findings of Jones and Allen's (2012) research, which show that students with the evaluativist level are still uncommon in first-year undergraduate students and are only found in the final years of their studies. Hofer and Sinatra (2010) stated that 'maturation' alone is not enough to trigger and encourage the development of one's epistemological understanding of physics. There is no guarantee that older individuals such as adults returning to college will be at the evaluativist level. Hofer and Sinatra (2010) also showed that most of them even have a multiplist level or even realist. This indicates that many university graduates still have a low level of epistemological understanding. Herein lies the problem of graduate competence that occurs in Indonesia.

The maturation referred to earlier is a form of intervention through lectures. Various developmental approaches imply that the appropriate educational intervention is to provide learning at a level just above its current level. It is much better to just put learning at its current level or a level far above it. This is in line with Vygotsky's (1978) well-known notion of the zone of proximal development, i.e., when the material or idea presented is outside its zone or reach, it will lead to confusion and a contradiction will occur in his mind. Based on this theory, if we already know with certainty the level of students' epistemological understanding, then we can design the most appropriate learning to increase the maturation of their epistemological understanding.

The theory of belief has implications for the realm of education (especially higher education) in changing epistemological beliefs. Hofer (2001) argues that the epistemological assumptions underlying critical thinking can be identified and prioritized in the teaching process. For example, by emphasizing that not all problems have only one correct solution. This introduces the fact that science evolves and some ideas are discarded to be replaced with new ones, and what may initially appear to be conflicting theories can sometimes be synthesized into new and more robust theoretical frameworks. All of this critical thinking (as well as epistemological rationale) can be prioritized in teaching and learning design.

The contribution of epistemological understanding to critical thinking skills is no longer a debate among researchers. However, based on data analysis, additional information was obtained that the epistemological understanding of physics was explained best in terms of personal taste and aesthetic judgment, while the lowest was ethical judgment. This explains that physics students are not very suitable if their critical thinking skills are built by emphasizing ethical judgment on their epistemological understanding of physics. However, the critical thinking skills of physics students are very suitable if they are built with an emphasis on personal taste and aesthetic judgment on their epistemological understanding of physics.

This new finding will provide new insights into the type of physics material that is required to instil good epistemological understanding in physics students. Based on data analysis, Physics materials should also emphasize (or at the very least integrate) issues of personal taste and aesthetic judgment. At first glance, these results attempt to combine immeasurable content such as taste and aesthetics, but this is worthwhile given that well-known physicists always rely on these two things to find satisfaction and happiness during their time as scientists.

5. Conclusions

According to the findings of this study, students in the physics department of the Faculty of Mathematics and Natural Sciences at Makassar State University have a medium level of epistemological understanding of physics. Students at Makassar State University's physics department, Faculty of Mathematics and Natural Sciences, have a medium level of critical thinking ability. Understanding the epistemology of physics has a direct and significant impact on the critical thinking skills of students in the Department of Physics' final semester. If students' critical thinking skills in physics learning need to be improved, physics epistemological understanding must first be improved. This study demonstrates that elements of epistemological understanding that are not present in physics learning have an impact on critical thinking skills. We can gain new knowledge by learning that philosophical studies of physics (such as physics ethics, physics aesthetics and so on) can be used as lecture materials to strengthen critical thinking skills.

6. Recommendations

This study is a basic research which is limited to examining the influence of variables in estimating students' intellectual development potential. This study also confirmed that epistemological understanding influences many other skill variables, such as creative thinking skills, science process skills and other types of skills. The results of this basic research can then be used to design development research, such as the design of learning forms that take into account the level of students' epistemological understanding. We propose that students' epistemological understanding be given more attention during the lecture process. This specific epistemological understanding can be well instilled through a type of philosophical-based physics learning. The new knowledge that we can gain is that philosophical studies of physics (such as physics ethics, physics aesthetics and so on) can also be used as lecture material to strengthen critical thinking skills. As a result, the recommendation for students and teachers in the world of physics, in both formal and non-formal education, or even in the field of solving life problems using physics, is to not ignore the values philosophy of physics that they are currently working on because it is the main ‘fuel’ that will keep them motivated to study and think critically.

References

Arafah, K., Arafah, A.N.B., Arafah, B. (2020). Self-concept and self-efficacy’s role in achievement motivation and Physics learning outcomes. Opción, 36, 1607-1623. https://dialnet.unirioja.es/servlet/articulo?codigo=7667445

Arafah, K. (2021). Analysis of quality of critical thinking skills test based on item response theory using R-program. Psychology and Education Journal, 58(1), 1167–1174. https://doi.org/10.17762/pae.v58i1.867

Arafah, K., Amin, B.D., Hakim, A. (2021). The development of higher order-thinking skills (HOTS) instrument assessment in Physics study. Journal of Physics: Conference Series, Phys.: Conf. Ser, 1899(1), 012140. 10.1088/1742-6596/1899/1

Arafah, K., Helmi., Malago, J.D. (2021). Profile of critical thinking skills on fluid mechanics material by senior high school students in makassar city. Multicultural Education, 7(1), 128-133.https://doi.org/10.5281/zenodo.4445157

Bailin, S., Case, R., Coombs, J. R., & Daniels, L. B. (1999). Conceptualizing critical thinking. *Journal of curriculum studies*, 31(3), 285-302. https://doi.org/10.1080/002202799183133

Barzilai, S., & Chinn, C. A. (2018). On the goals of epistemic education: Promoting apt epistemic performance. *Journal of the Learning Sciences, 27(3), 353-389*. https://doi.org/10.1080/10508406.2017.1392968

Barzilai, S., & Weinstock, M. (2015). Measuring epistemic thinking within and across topics: A scenario-based approach. *Contemporary Educational Psychology, 42, 141–158*. https://doi.org/10.1016/j.cedpsych.2015.06.006

Basham, G., Irwin, W., Nardone, H., & Wallace, J.M. (2013). *Critical thinking: A students' introduction. McGraw Hill Education.*

Baxter Magolda, M. B. (2004). Evolution of a constructivist conceptualization of epistemological reflection. *Educational Psychologist, 39(1), 31-42*. https://doi.org/10.1207/s15326985ep3901_4

Becker, J. M., Klein, K., & Wetzels, M. (2012). Hierarchical latent variable models in PLS-SEM: guidelines for using reflective-formative type models. *Long range planning, 45(5-6), 359-394*. http://www.elsevier.com/locate/lrp

Bishop, R. C. (2011). Metaphysical and epistemological issues in complex systems. *Philosophy of complex systems (10). 105-136*. North-Holland, Elsevier BV.

Bråten, I., & Strømsø, H. I. (2004). Epistemological beliefs and implicit theories of intelligence as predictors of achievement goals. *Contemporary Educational Psychology, 29(4), 371–388.* https://doi.org/10.1016/j.cedpsych.2003.10.001

Chandler, M., Sokol, B. W., & Wainryb, C. (2000). Beliefs about truth and beliefs about rightness. *Child Development, 71(1), 91–97.* https://doi.org/10.1111/1467-8624.00122

Chinn, C. A., Buckland, L. A., & Samarapungavan, A. L. A. (2011). Expanding the dimensions of epistemic cognition: Arguments from philosophy and psychology. *Educational Psychologist, 46(3), 141-167.* https://doi.org/10.1080/00461520.2011.587722

diSessa, A. A. (1993). Toward an epistemology of physics. *Cognition and instruction, 10(2-3), 105-225.* https://doi.org/10.1080/07370008.1985.9649008

Ennis, R. H. (2015). Critical thinking: A streamlined conception. In The Palgrave handbook of critical thinking in higher education (pp. 31-47). Palgrave Macmillan, New York. Editors: Martin Davies, Ronald Barnett.

Facione, Peter A., Gittens, A. C (2016). *Think Critically. Insight Assessment.* Pearson Education: Englewood Cliffs, NJ.

Hair Jr, J. F., Howard, M. C., & Nitzl, C. (2020). Assessing measurement model quality in PLS-SEM using confirmatory composite analysis. *Journal of Business Research*, 109, 101-110. https://doi.org/10.1016/j.jbusres.2019.11.069

Hair Jr, J. F., Sarstedt, M., Pieper, T. M., & Ringle, C. M. (2012). The use of partial least squares structural equation modeling in strategic management research: a review of past practices and recommendations for future applications. *Long range planning, 45(5-6), 320-340.* https://doi.org/10.1016/j.lrp.2012.09.008

Hammer, D. (1994). Epistemological beliefs in introductory physics. *Cognition and instruction, 12(2), 151-183.* https://www.jstor.org/stable/3233679

Hammer, D. (2000). Student resources for learning introductory physics. American Journal of Physics, 68, S52-S59. https://doi.org/10.1119/1.19520

Hammer, D., & Elby, A. (2003). Tapping epistemological resources for learning physics. *The Journal of the Learning Sciences, 12(1), 53-90.* https://doi.org/10.1207/S15327809JLS1201_3

Hofer, B. K. (2001). Personal epistemology research: Implications for learning and teaching. *Educational Psychology Review, 13(4), 353–383*. https://doi.org/10.1023/A:1011965830686

Hofer, B. K. (2004). Exploring the dimensions of personal epistemology in differing classroom contexts: Student interpretations during the first year of college. *Contemporary Educational Psychology, 29(2), 129–163*. https://doi.org/10.1016/j.cedpsych.2004.01.002

Hofer, B. K., & Sinatra, G. M. (2010). Epistemology, metacognition, and self-regulation: Musings on an emerging field. *Metacognition and learning, 5(1), 113-120.* DOI: 10.1007/s11409-009-9051-7

Jho, H. (2018). Beautiful physics: re-vision of aesthetic features of science through the literature review. *Journal of the Korean Physical Society, 73(4), 401-413.* DOI: 10.3938/jkps.73.401

Jones, S. & Allen, J. (2012). Evaluating Psychology Students' Library Skills and Experiences. *Psychology Teaching Review,* 18*(2), 94-115*. Retrieved August 14, 2022 from https://www.learntechlib.org/p/91445/.

Kuhn, D., & Park, S. H. (2005). Epistemological understanding and the development of intellectual values. *International Journal of educational research, 43(3), 111-124*. www.elsevier.com/locate/ijedures

Kuhn, D., Cheney, R., & Weinstock, M. (2000). The development of epistemological understanding. *Cognitive Development, 15(3), 309–328*. https://doi.org/10.1016/S0885-2014(00)00030-7

Mainali, B. P. "Critical Thinking for Quality Education". Academic Voices: A Multidisciplinary Journal, vol. 1, Aug. 2011, 6-12. https//doi:10.3126/av.v1i0.5300

May, D. B., & Etkina, E. (2002). College physics students' epistemological self-reflection and its relationship to conceptual learning. *American Journal of Physics, 70(12), 1249-1258.*

Ryan, T.P. (2013). *Sample size determination and power*. Singapore: John Wiley & Sons.

Schommer, M. (1990). Effects of beliefs about the nature of knowledge on comprehension. *Journal of Educational Psychology, 82*(3), 498–504. https://doi.org/10.1037/0022-0663.82.3.498

Stathopoulou, C., & Vosniadou, S. (2007). Exploring the relationship between physics-related epistemological beliefs and physics understanding. *Contemporary Educational Psychology, 32*(3), 255–281. https://doi.org/10.1016/j.cedpsych.2005.12.002

Vygotsky, L. S. (1978). Mind in society: The development of higher psychological processes. Harvard University Press.

Żyluk, N., Karpe, K., Michta, M., Potok, W., Paluszkiewicz, K., & Urbański, M. (2018). Assessing levels of epistemological understanding: The Standardized epistemological understanding assessment (SEUA). Topoi, 37(1), 129-141. https://doi.org/10.1007/s11245-016-9381-4