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Electromotive Forces on Multitier Instruments (EFoMI): Development to measure student misconception with Rasch

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Abstract: This research aims to develop Electromotive Forces on Multitier Instruments (EFoMI) in measuring student misconceptions. Method: This development research uses 4D design. Participants in this research were 19 students (10 Females and 9 Males) in one of the Bandung junior high schools. The instruments used are those developed in this research. The Rasch analysis was used to identify the feasibility of EFoMI using WINSTEPS 4.4.5 software which had previously been included in the conceptual categories of Sound Understanding (SU), Partial Positive (PP), Partial Negative (PN), No Understanding (NU), Misconception (MC), and No Coding (NC). Meanwhile, VOSviewer analysis was carried out to look for research trends related to misconceptions. Results: The results show the construct validity and fit statistics which meet all criteria. the reliability of EFoMI, namely 0.82, is in the Very Good category. The difficulty level of EFoMI is evenly distributed, the discrimination in the Very Good category, and no gender bias was detected from EFoMI. The distribution of students' conceptions includes SU= 12%, PP= 4%, PN= 45%, NU= 7%, MC= 27%, and NC=4%. These results have several implications in the field of education. An example is EFoMI's success in identifying student misconceptions, thus it can be an alternative for teachers in developing or identifying student misconceptions. Then, by knowing students' initial conceptions, teachers can develop learning tools that are more focused on student misconceptions and based on data. Likewise, to develop or use teaching materials more effectively by knowing the areas where students often experience misconceptions.
Keywords: electromotive forces; conception; rasch

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Introduction

Electromotive Forces (EMF) is one of the concepts studied by junior high school students in Indonesia. However, this section does not discuss induced EMF, but rather the potential differences that exist in an electrical circuit. Thus, actually the term EMF in this study is a misnomer because batteries do not produce force in Newton units. Moreover, the terms EMF and electric potential difference are not the same thing. Apart from that, some of the main differences include EMF is the cause and potential difference is the effect (Ho et al., 2022). The EMF is the amount of energy imparted to one coulomb of charge to go around the entire circuit, while the electric potential difference is the amount of energy used by one coulomb of charge (Ho et al., 2022; Sarwono et al., 2022; Waqar et al., 2023). This concept is discussed at the junior high school level in Indonesia, generally found in the dynamic electricity chapter (Noftiana et al., 2019). The dynamic electricity learning at junior high school level can be seen in Figure 1.

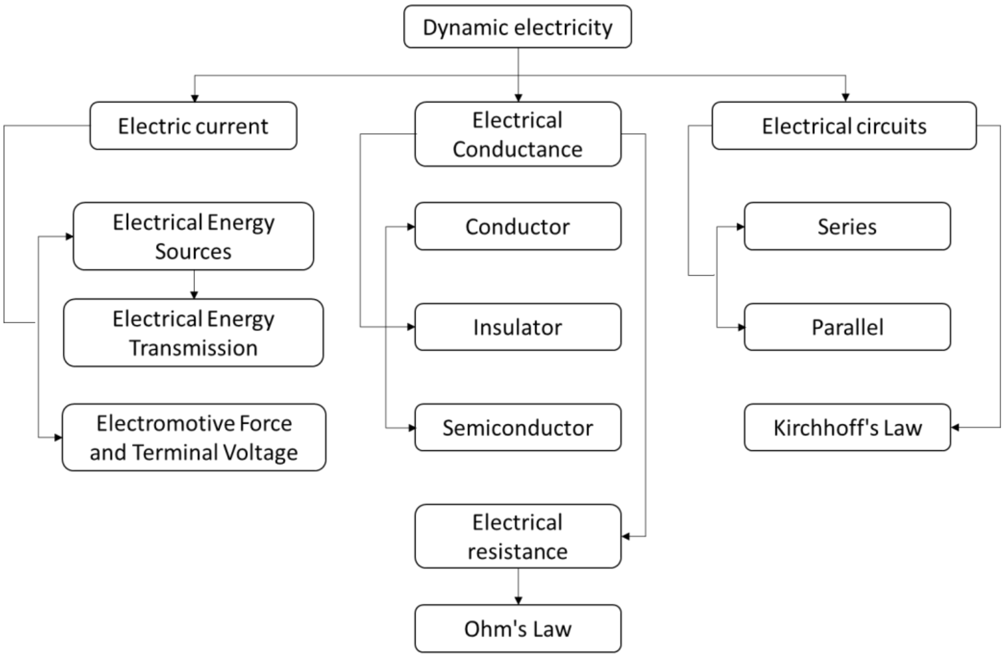


Figure 1. Dynamic Electricity Concept Map for Junior High School

Figure 1 shows the dynamic electricity concepts that students learn at the junior high school level. The EMF part in this case is often discussed with terminal voltage, internal resistance, series, parallel, and series-parallel resistor networks, etc. A device for supplying electrical energy to a circuit is called a source called EMF. Emf shows how much energy is supplied to the circuit to move one coulomb of charge throughout the circuit and its value is greater than the potential difference between two points (Waqar et al., 2023). This concept is one of the concepts that students often encounter in everyday life, but the term is rarely heard thus it feels new to students.

The EMF concept in this study is often confused with the EMF section of electromagnetic induction at the high school level. Thus, it needs to be deepened, both in terms of teaching resources, test instruments and learning media because it is included in an abstract discussion (Ho et al., 2022). Several studies show that there are misconceptions about EMF, as shown in Table 1.

Table 1. Examples of Misconceptions about EMF

No	Author	Journal	SJR	Misconceptions
1	Ho et al., 2022	European Journal of Physics	Q2	EMF is often considered equivalent to potential difference or voltage.
2	Rodrigues et al., 2018	Journal of Chemical Education	Q2	The use of the terms EMF and electrical potential difference by undergraduate students probably arises because these two concepts are measured experimentally with a voltmeter, and this is one of the causes of misconceptions about the EMF concept.
3	Alicki et al., 2021	Physical Chemistry Chemical Physics	Q2	The term Electromotive Force (EMF) should be replaced with Electromotive Pump (EMP) to better describe the basic physical mechanism that drives the circulation of electric current in a closed circuit.

No	Author	Journal	SJR	Misconceptions
4	Zuza et al., 2016	European Journal of Physics	Q2	The EMF misconceptions occur not only because the term is wrong from the start, but the phenomenon also often seems difficult to observe and understand.
5	Garzón et al., 2014	American Journal of Physics	Q2	The EMF is the value of the force made by the device and this force is necessary for moving the electrons There is confusion between the nature of EMF and the nature of potential difference

Table 1 shows the misconceptions that occur regarding EMF. Thus, the aim of this research is to develop Electromotive Forces on Multitier Instruments (EFoMI) in measuring student misconceptions. This research can contribute to the completeness of learning resources related to the concept of EMF at the junior high school level, which is currently still rarely found for multi-tier instruments which are instruments for diagnosing misconceptions (Sari et al., 2023). Especially discussing misconceptions because misconceptions often occur in abstract physics concepts (Jayanti & Rahayu, 2019). Meanwhile, Rasch analysis is used to identify the feasibility of the instrument being developed.

Method

Design

This development research uses the Define, Design, Develop, and Disseminate (4D) design. This design is often carried out by several researchers to develop products, one of which is instrument development (e.g. Aripiani et al., 2023; Istiyono et al., 2020; Samsudin et al., 2021). Meanwhile, each stage in 4D design is explained in Figure 2.

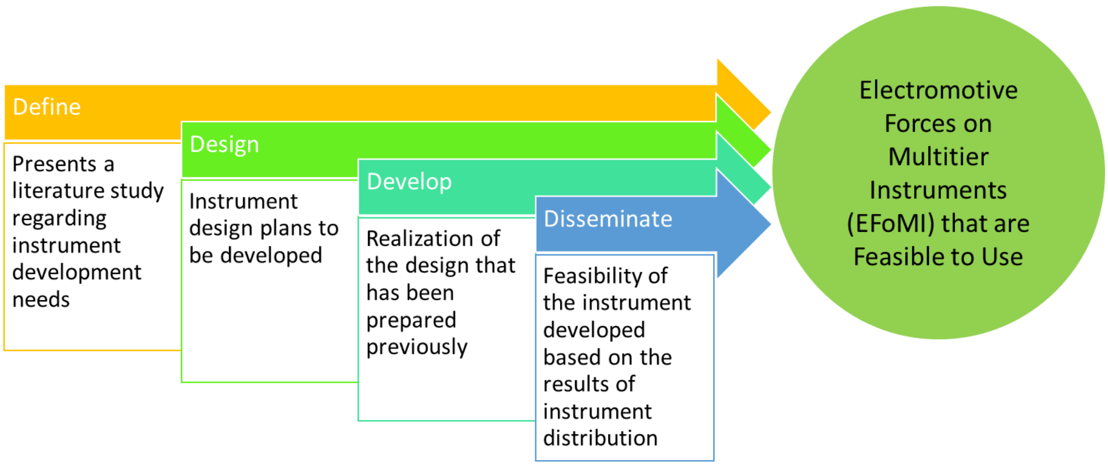


Figure 2. The 4D Design for EFoMI Development

Participants

Participants in this research were 19 students (10 Females and 9 Males) in one of the Bandung junior high school. The map of the area where the research was conducted is in Figure 3.

Figure 3. The Map of The Research Area in Bandung (Source By Google Map)

Data Analysis

Before the data is analyzed, students' answers are first entered based on conception categories (Aminudin et al., 2019), namely Sound Understanding (SU), Partial Positive (PP), Partial Negative (PN), No Understanding (NU), Misconception (MC), and No Coding (NC). In general, the Rasch analysis was used to identify the feasibility of EFoMI using WINSTEPS 4.4.5 software. Rasch analysis is very supportive for analyzing the feasibility of a test instrument (e.g. Chan et al., 2014; Planinic et al., 2019; Royal et al., 2014; Soeharto & Csapó, 2021). Another additional analysis is the VOSviewer analysis which is carried out to analyze ongoing research trends (Deti & Mandasari, 2021; Hatami et al., 2021; Samsudin, Novia, et al., 2023). Meanwhile, Rasch analysis for other parts includes construct validity analysis (Table 23 in WINSTEPS 4.4.5) and fit statistics (Table 10 in WINSTEPS 4.4.5), reliability analysis (Table 3.1 in WINSTEPS 4.4.5), level of difficulty and discrimination. (Table 10 in WINSTEPS 4.4.5), and gender bias (Table 30 in WINSTEPS 4.4.5). The map analysis of the distribution of potential misconceptions was carried out using the Variable (Wright) map (Table 1 in WINSTEPS 4.4.5).

Results and Discussion

This section will be discussed based on Define, Design, Develop, and Disseminate (4D) design.

Define

Based on the results of literature studies in Scopus articles, a search was carried out using the following criteria: (TITLE-ABS-KEY (misconception) AND TITLE-ABS-KEY (physics)) AND PUBYEAR > 2018 AND PUBYEAR < 2024 AND (LIMIT-TO (SUBJAREA, "soci")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (PUBSTAGE, "final")) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (LANGUAGE, "english")). Based on this search, 133 articles were obtained from 56 journals for further analysis. The list of the top 10 journals used as analysis for searching misconception data can be seen in Figure 4.

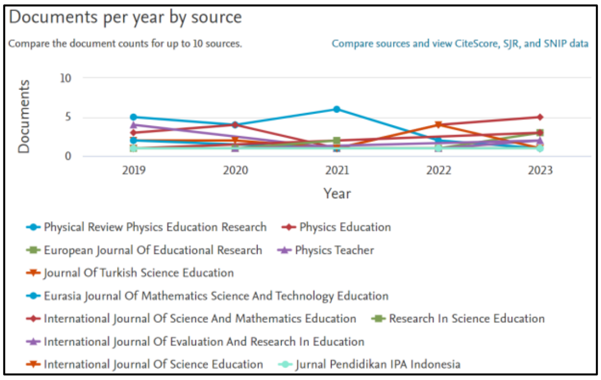


Figure 4. List of the Top 10 Journals From the Sample

Meanwhile, the results obtained were analyzed using VOSviewer bibliometric analysis. The results obtained based on the analysis of the article title can be seen in Figure 5.

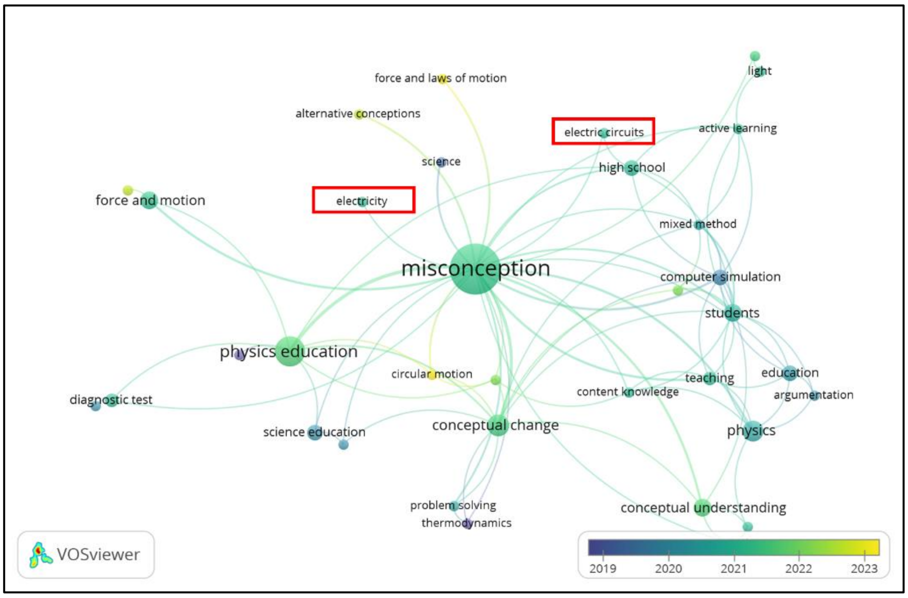


Figure 5. VOSviewer Analysis Results on the Title

Based on Figure 5, it can be seen that misconceptions occur in various physics concepts, one of which is the concept of "electricity" and "electric circuits". Things related to the concept of electricity are the basis for this development research. Especially instruments related to measuring conceptions, one of which is misconceptions about physics concepts. While analyzing by country on the Scopus articles obtained, it is known that research related to misconceptions was carried out in several countries as in Figure 6.

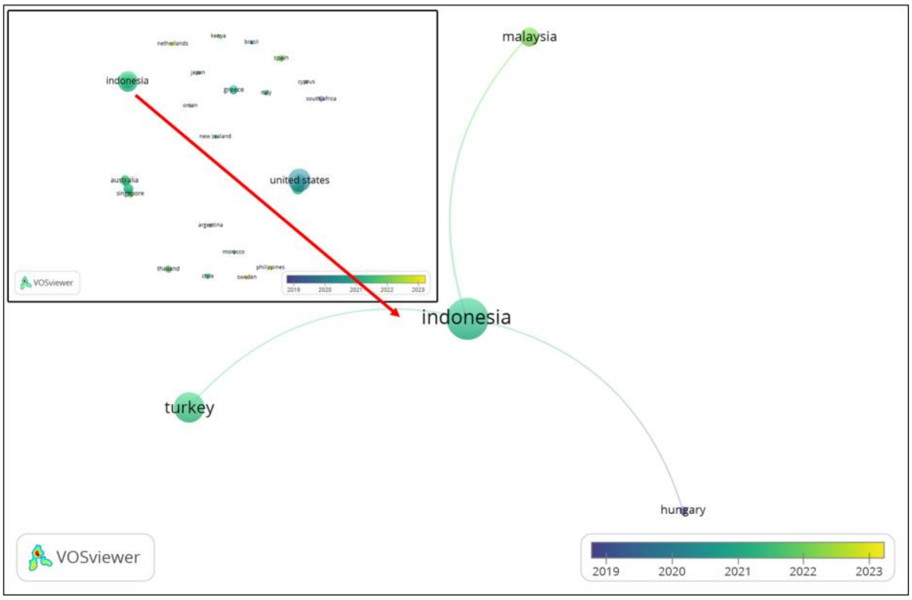


Figure 6. VOSviewer Analysis Results on the Country

Based on Figure 6, research related to this misconception is still popular. This can be seen from the colors in Indonesia which are the same as around 2021-2022. Thus, the development research is also included in the research trend in Indonesia. Apart from that, writers from Indonesia are also seen collaborating with researchers from outside, such as Turkey, Malaysia and Hungary.

Design

The design developed for the EFoMI instrument is a four-tier on multi-tier instrument design as developed by several researchers (e.g. Kaltakci-Gurel et al., 2017; Kaniawati et al., 2019; Sari et al., 2023). The sequence of the four-tier design is as follows. Tier 1 is the problem tier. Tier 2 is the level of confidence in the answers in tier 1. Tier 3 is the reasons for the answers given in Tier 1. In Tier 3, it has an open-ended format, so students can fill in the reasons based on their understanding. Meanwhile, Tier 4 is the level of confidence in the reasons given in Tier 3.

Develop

Development was carried out after the EFoMI instrument design was created. Development in the form of realizing the EFoMI design into Google Form. Examples of instruments that have been developed can be seen in Figure 7.

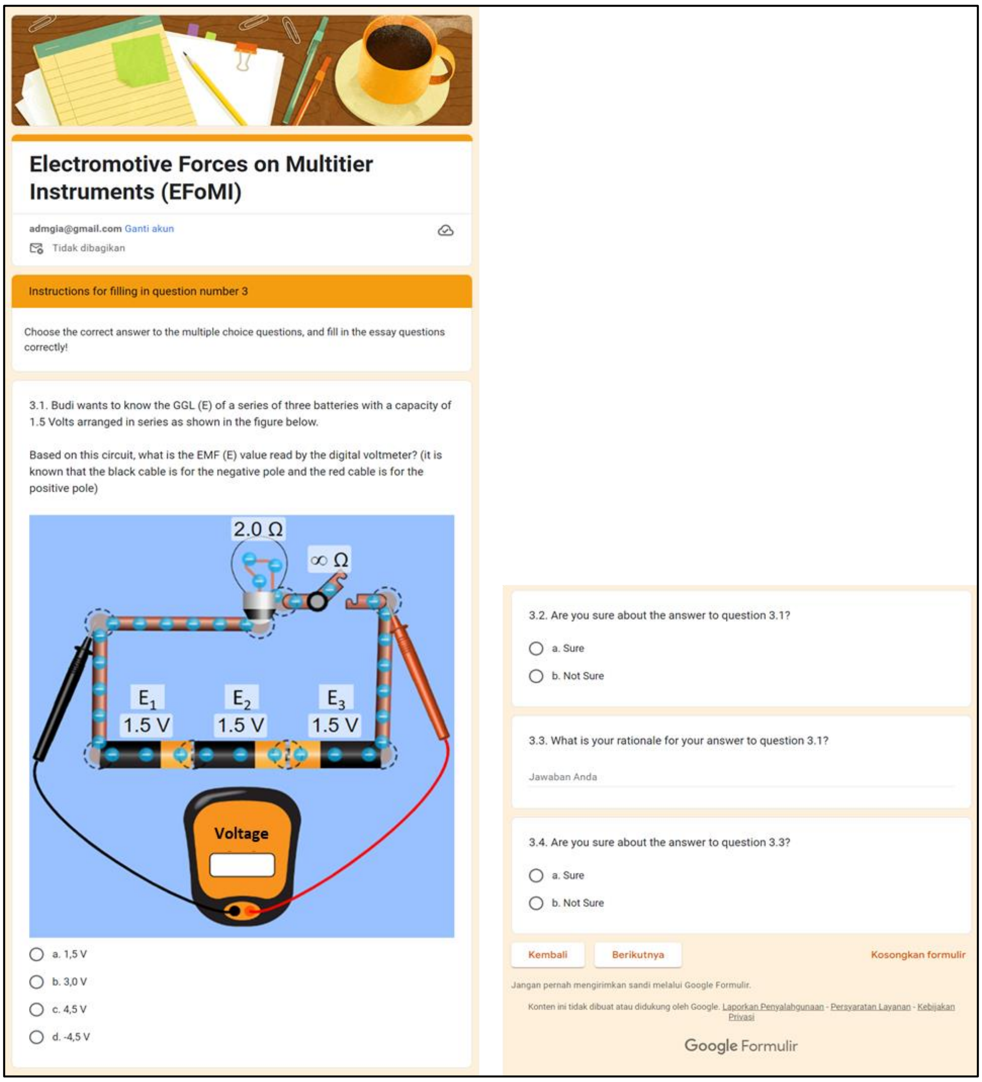


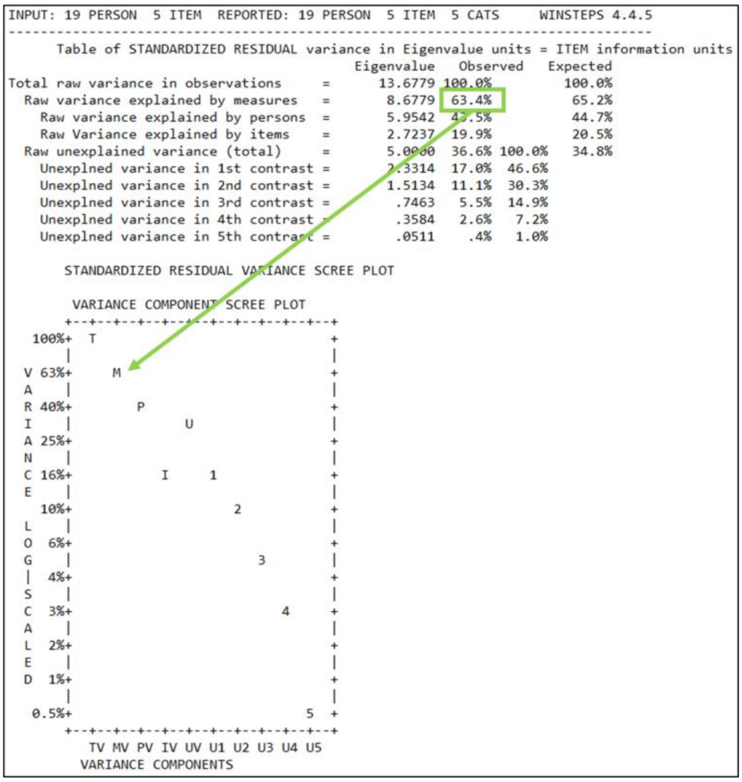
Figure 7. Example Questions on EFoMI

Disseminate

The results obtained are based on the dissemination of EFoMI, including regarding the feasibility of EFoMI and the mapping of student answers for EFoMI potential misconceptions.

Feasibility of EFoMI

The feasibility of EFoMI is reviewed from various aspects, including Validity (Construct and Fit Statistics), Reliability, Difficulty Level, Discrimination, and Gender Bias. To test construct validity, Rasch analysis was carried out for the Dimensionality Map output can be seen in Figure 8.



```
INPUT: 19 PERSON  5 ITEM  REPORTED: 19 PERSON  5 ITEM  5 CATS     WINSTEPS 4.4.5
--------------------------------------------------------------------------------
      Table of STANDARDIZED RESIDUAL variance in Eigenvalue units = ITEM information units
                                          Eigenvalue   Observed   Expected
Total raw variance in observations     =     13.6779 100.0%         100.0%
  Raw variance explained by measures   =      8.6779  63.4%          65.2%
    Raw variance explained by persons  =      5.9542  43.5%          44.7%
    Raw Variance explained by items    =      2.7237  19.9%          20.5%
  Raw unexplained variance (total)     =      5.0000  36.6% 100.0%   34.8%
    Unexplned variance in 1st contrast =      2.3314  17.0%  46.6%
    Unexplned variance in 2nd contrast =      1.5134  11.1%  30.3%
    Unexplned variance in 3rd contrast =       .7463   5.5%  14.9%
    Unexplned variance in 4th contrast =       .3584   2.6%   7.2%
    Unexplned variance in 5th contrast =       .0511    .4%   1.0%

       STANDARDIZED RESIDUAL VARIANCE SCREE PLOT

        VARIANCE COMPONENT SCREE PLOT
```


Figure 8. Dimensionality Map on EFoMI

Figure 8 shows that the validity of the EFoMI construct in the Rasch model is a validity test based on item dimensionality on the raw variance value explained by measures. The result obtained was 63.4%, which according to Lee et al. (2021) was included in the Special criteria because it was >60%. Thus, from a construction perspective, EFoMI is identified as valid.

Further analysis of the validity of this construct is validity in terms of Fit Statistics. The quality of the items can be seen in the output, namely the fit order items from the MNSQ, ZSTD and PT Measur Corr outfit values. The results obtained can be seen in Figure 9.

INPUT: 19 PERSON 5 ITEM REPORTED: 19 PERSON 5 ITEM 5 CATS WINSTEPS 4.4.5

PERSON: REAL SEP.: 2.22 REL.: .83 ... ITEM: REAL SEP.: 2.07 REL.: .81

ITEM STATISTICS: MISFIT ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD		PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	ITEM
3	52	18	-1.39	.41	1.80	1.16	2.00	1.07	A	.83	.89	70.6	78.5	I3
2	20	18	.93	.30	1.27	.71	1.84	1.19	B	.60	.56	52.9	65.1	I2
1	27	19	.48	.25	1.11	.40	.79	-.20	C	.60	.59	77.8	65.9	I1
5	39	18	-.26	.24	.83	-.56	.69	-.51	b	.76	.72	47.1	50.6	I5
4	30	18	.24	.24	.81	-.48	.66	-.66	a	.62	.63	41.2	39.4	I4
MEAN	33.6	18.2	.00	.29	1.17	.2	1.20	.2				57.9	59.9	
P.SD	11.0	.4	.80	.06	.36	.7	.59	.8				14.0	13.5	

Figure 9. Fit Statistic on EFoMI

The respective criteria are 0.5 < x < 1.5 for MNSQ (Green Box), -2 < x < +2 for ZSTD (Blue Box), and 0.4 < x < 0.85 for PT Measur Corr (Orange box) (Idulfilastri et al., 2021). Meanwhile, the EFoMI results for all question items in Figure meet all the specified criteria. Thus, when these three are met then all EFoMI items fall into valid criteria based on Fit Statistics. After this validity test, the next analysis is reliability analysis.

Reliability analysis on Rasch is carried out through Summary Statistics (Samsudin et al., 2021). The results obtained for EFoMI reliability can be seen in Figure 10.

```
INPUT: 19 PERSON  5 ITEM  REPORTED: 19 PERSON  5 ITEM  5 CATS     WINSTEPS 4.4.5
--------------------------------------------------------------------------------

     SUMMARY OF 18 MEASURED (NON-EXTREME) PERSON
-------------------------------------------------------------------------------
|          TOTAL                         MODEL         INFIT        OUTFIT    |
|          SCORE     COUNT     MEASURE    S.E.      MNSQ   ZSTD   MNSQ   ZSTD |
|-----------------------------------------------------------------------------|
| MEAN       9.3       4.8        .08      .69       .89   -.20   1.09    .03 |
|  SEM       1.2        .2        .46      .11       .26    .27    .53    .24 |
| P.SD       5.1        .9       1.88      .47      1.06   1.13   2.17    .99 |
| S.SD       5.2        .9       1.93      .48      1.09   1.17   2.23   1.02 |
| MAX.      17.0       5.0       1.98     2.32      4.93   3.52   9.90   3.50 |
| MIN.       1.0       1.0      -4.88      .41       .00  -1.65    .00  -1.65 |
|-----------------------------------------------------------------------------|
| REAL RMSE    .87 TRUE SD    1.67  SEPARATION  1.92  PERSON RELIABILITY  .79 |
|MODEL RMSE    .84 TRUE SD    1.68  SEPARATION  2.01  PERSON RELIABILITY  .80 |
| S.E. OF PERSON MEAN = .46                                                   |
-------------------------------------------------------------------------------
  MINIMUM EXTREME SCORE:      1 PERSON 5.3%

     SUMMARY OF 19 MEASURED (EXTREME AND NON-EXTREME) PERSON
-------------------------------------------------------------------------------
|          TOTAL                         MODEL         INFIT        OUTFIT    |
|          SCORE     COUNT     MEASURE    S.E.      MNSQ   ZSTD   MNSQ   ZSTD |
|-----------------------------------------------------------------------------|
| MEAN       8.8       4.8       -.26      .76                                |
|  SEM       1.3        .2        .55      .13                                |
| P.SD       5.3        .9       2.33      .53                                |
| S.SD       5.5        .9       2.39      .55                                |
| MAX.      17.0       5.0       1.98     2.32                                |
| MIN.        .0       1.0      -6.36      .41                                |
|-----------------------------------------------------------------------------|
| REAL RMSE    .95 TRUE SD    2.12  SEPARATION  2.22  PERSON RELIABILITY  .83 |
|MODEL RMSE    .93 TRUE SD    2.14  SEPARATION  2.31  PERSON RELIABILITY  .84 |
| S.E. OF PERSON MEAN = .55                                                   |
-------------------------------------------------------------------------------
PERSON RAW SCORE-TO-MEASURE CORRELATION = .87
CRONBACH ALPHA (KR-20) PERSON RAW SCORE "TEST" RELIABILITY = .82  SEM = 2.24

     SUMMARY OF 5 MEASURED (NON-EXTREME) ITEM
-------------------------------------------------------------------------------
|          TOTAL                         MODEL         INFIT        OUTFIT    |
|          SCORE     COUNT     MEASURE    S.E.      MNSQ   ZSTD   MNSQ   ZSTD |
|-----------------------------------------------------------------------------|
| MEAN      33.6      18.2        .00      .29      1.17    .25   1.20    .18 |
|  SEM       5.5        .2        .40      .03       .18    .34    .30    .40 |
| P.SD      11.0        .4        .80      .06       .36    .67    .59    .79 |
| S.SD      12.3        .4        .89      .07       .41    .75    .66    .89 |
| MAX.      52.0      19.0        .93      .41      1.80   1.16   2.00   1.19 |
| MIN.      20.0      18.0      -1.39      .24       .81   -.56    .66   -.66 |
|-----------------------------------------------------------------------------|
| REAL RMSE    .35 TRUE SD     .72  SEPARATION  2.07  ITEM   RELIABILITY  .81 |
|MODEL RMSE    .29 TRUE SD     .74  SEPARATION  2.51  ITEM   RELIABILITY  .86 |
| S.E. OF ITEM MEAN = .40                                                     |
-------------------------------------------------------------------------------
ITEM RAW SCORE-TO-MEASURE CORRELATION = -1.00
Global statistics: please see Table 44.
UMEAN=.0000 USCALE=1.0000
```

Figure 10. Fit Statistic on EFoMI

Cronbach alpha in Rasch analysis shows the interaction value between person and item from the EFoMI instrument which is 0.82. Meanwhile, for the interpretation of the Cronbach alpha value according to (Muhammad et al., 2023), if the value is >0.8 then it is in the Very Good category.

Another analysis that can be carried out is Difficulty Level. This section is actually found in the Figure about Measure and P.SD (Purple Box) with a Standard Deviation value (SD = 0.80). According to Mokshein et al. (2019), a logit value of 0.0 + 1SD is a difficult group, greater than + 1SD is a very difficult question, logit 0.0 - 1SD is an easy question, and smaller than - 1SD is a very easy question. The criteria obtained from EFoMI for difficulty level analysis are in Table 2.

Table 2. Difficulty Level on EFoMI

Question Numbers	Difficulty Level (DL)			
	DL < -0.80 Very Easy	-0.80 ≤ DL < 0,0 Easy	0,0 ≤ DL < 0.80 Difficult	0.80 ≤ DL Very Difficult
1			0.48	
2				0.93
3	-1.39			
4			0.24	
5		-0.26		

Based on Table 2, it can be seen that the distribution of EFoMI is evenly distributed according to the level of difficulty. This is good because it can meet all levels of difficulty evenly.

The next analysis is about Discrimination. The same value is shown by the image about PT Measur Corr (orange box). According to (Yulianto & Widodo, 2020), the value of Point-measure correlation (PTMEASURE-AL CORR) can also be used to determine the differentiating power of an instrument and can be seen in Table 3.

Table 3. Discrimination on EFoMI

Question Numbers	Difficulty Level (DL)			
	PT-MC ≤ 0,19 Bad	0,20 ≤ PT-MC < 0,30 Not good	0,30 ≤ PT-MC < 0,40 Good	0,40 ≤ PT-MC Very Good
1				0.60
2				0.60
3				0.83
4				0.62
5				0.76

The results in Table 3 show that all question numbers on EFoMI have very good Discrimination scores. The final analysis is the quality of gender bias. This is to identify whether EFoMI benefits only one gender or is good for all. The results obtained can be seen in Figure 11.

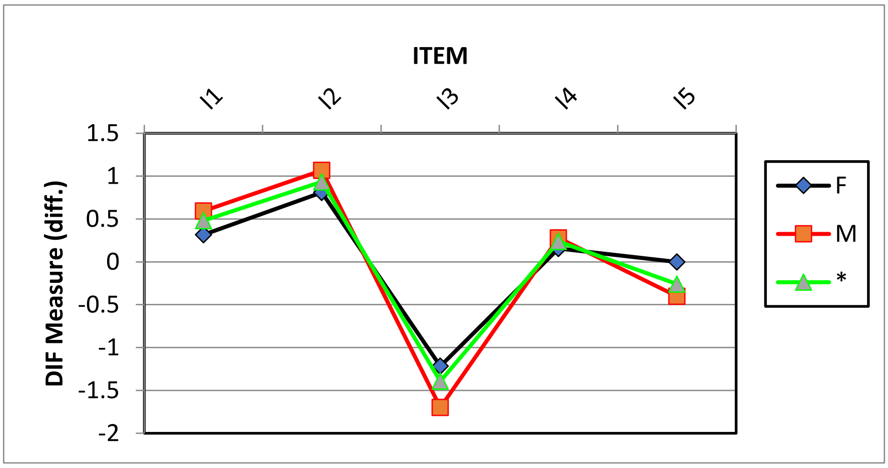


Figure 11. Gender Bias on EFoMI

Based on Figure 11, the green line is the line resulting from Rasch analysis, which is a reference in determining gender bias. Meanwhile, the black line is for the Female gender, and the red line is for the Male gender. The results obtained show that there is no significant deviation between the black and red lines and the reference line (green line). Thus, it can be said that EFoMI has no detectable gender bias.

Mapping of Student Answers

The mapping carried out was a comparison of the potential misconceptions of each participant (person) compared to the quality of the EFoMI (item). The distribution of potential misconceptions for each participant can be seen in Figure 12.

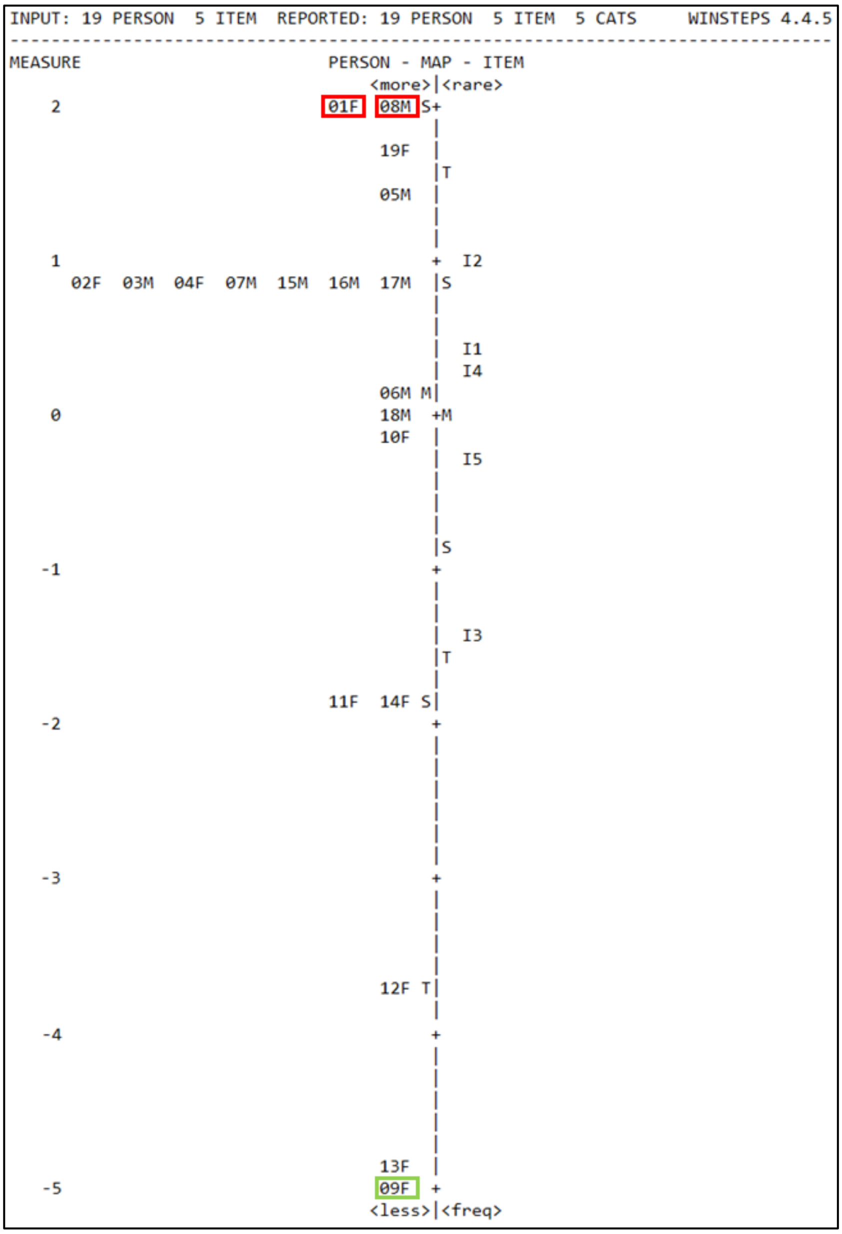


Figure 12. Mapping the Distribution of Potential Misconceptions

Figure 11 shows the comparison between person and item. The red boxes (participants with codes 01F and 08M) are people (participants) who have a high potential for misconceptions in answering the EFoMI. Numbers such as 01 indicate the order of participants, while codes F or M indicate the gender Female or Male for each participant. Meanwhile, the green box (09F) is the participant with the least potential for misconceptions. Each question identified has a distribution of levels of difficulty, as explained in Table 1. The general analysis to map the distribution of students' conceptions can be seen in Figure 13.

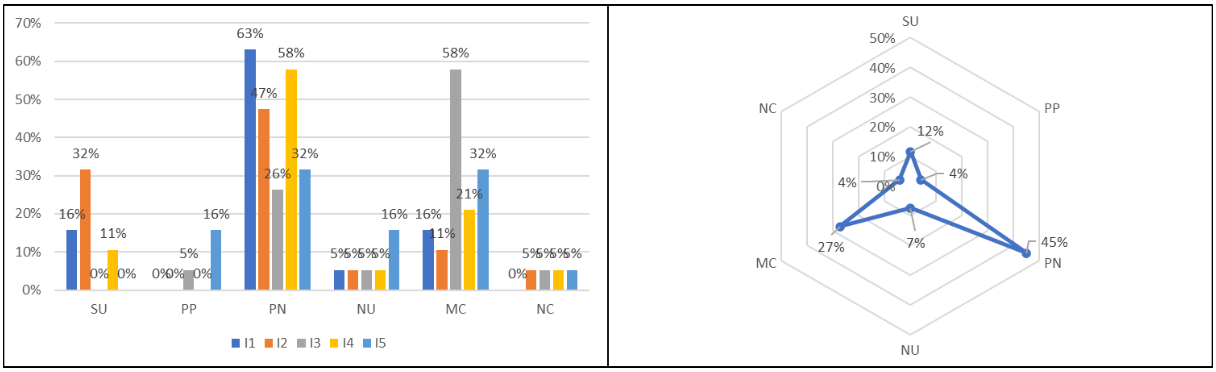


Figure 13. Clear Line Drawings Are Essential

The results show that students' conceptions are dominated by the PN category. Meanwhile, the smallest is found in the NU conception. The MC category has a percentage of 27%, and is the second highest after PN. This shows that the dominance of students' understanding regarding electromotive forces is still not enough. It can be seen that there are still many misconceptions being detected. It is not surprising because this concept is an abstract concept (e.g. Bakri et al., 2019; Ho et al., 2022) and indeed many misconceptions in physics occur in abstract concepts (e.g. Samsudin, et al., 2023; Suhandi et al., 2017). In Figure 13, it can be seen that the highest misconceptions are found in items with code I3 (gray color bars) with a percentage of (58%). This conception is related to the question in Figure 7 where the amount of EMF in a battery or galvanic cell is expressed in the form of an equation:

$$\varepsilon = V + Ir \qquad (1)$$

Note:
ε = Electromotive Forces (EMF)
V = Terminal Voltage
I = Electric Current
r = Resistance in Source

Apart from that, as explained in the initial section, this misconception occurs due to several factors. Several factors include the use of the term EMF which does not yet describe how it works, so there is a recommendation to change it to Electromotive Pump (EMP) (Alicki et al., 2021). Apart from that, the use of a voltmeter measuring instrument is also a factor in confusion between EMF and potential difference (Garzón et al., 2014; Ho et al., 2022; Rodrigues et al., 2018; Zuza et al., 2016).

Conclusion

The results show that EFoMI is suitable for use because it can measure students' conceptions, especially misconceptions about the concept of electromotive forces. This is supported by the results of construct validity and fit statistics which meet all criteria. Likewise, the reliability of EFoMI, namely 0.82, is in the Very Good category. Apart from that, the difficulty level of EFoMI is evenly distributed and the Discrimination scores from EFoMI are all in the Very Good category. No gender bias was detected from EFoMI. Besides that, the distribution of students' conceptions includes Sound Understanding (SU=12%), Partial Positive (PP=4%), Partial Negative (PN=45%), No Understanding (NU=7%), Misconception (MC=27%), and No Coding (NC=4%).

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