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Multiple representations (MR)-based instructional approach in support of physics identity and physics teachers' identity development: Design considerations

Nuril Munfaridah[1]*, Martin Goedhart[2]

[1]Universitas Negeri Malang, Semarang St. No. 5, Malang, 65145, Indonesia
[2]University of Groningen, 9712 CP Groningen, Netherlands
e-mail: nuril.munfaridah.fmipa@um.ac.id
* Corresponding Author.

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Abstract: In this paper, we describe the intervention and the context of implementation of a multiple representations (MR)-based instructional approach as a classroom practice in an first-year thermodynamics course for preservice physics teachers at an Indonesian university. We argue that the implementation of this approach will contribute to the enhancement of students' conceptual understanding and problem-solving skills. By enhancing those two aspects, we intend to contribute to their development of physics identity and physics teacher identity. We illustrate how this MR approach is applied in the classroom and describe how the relationship between the aspects of this approach interacts with physics identity and physics teacher identity. During lessons the teacher used real-life examples and students were encouraged to use different representations when they solved problems in small groups. The students realized that learning physics could involve many representations and might increase their interest to physics. However, we found some situations that did not match our expectations. For instance, most of the students were more interested when the problems were in the form of mathematical representation. In addition, we found that some students were inactive in the class. Therefore, it is necessary to think as educators about how to provide a positive learning experience to stimulate the development of student's identity. This work exemplifies how physics educators can stimulate physics and physics teacher identity formation in their physics courses as a preparation for future physics teachers.

Keywords: multiple representations; physics identity; physics teacher identity

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Introduction

The development of physics identity and physics teacher identity of preservice physics teachers is highly dependent on their performance in physics, and thus with their conceptual understanding and problem-solving skills (Hazari et al., 2010). Physics identity is defined as a disciplinary identity where the individual sees him/herself and is seen by others as a physics person (Wulff et al., 2011). It is obvious that the development of physics identity is closely related with a person's knowledge acquisition. As a matter of fact, Potvin and Hazari (2014) have shown that the conceptualization of an individual as a certain kind of person can strongly influence conceptual understanding, which is one of the manifestations of individual educational outcomes. In physics courses, the development of physics teacher identity and physics identity can be mutually supportive in the development of career professionalism as a physics teacher (Chung-Parsons & Bailey, 2019).

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Teacher identity has been defined as “being recognized as a certain kind of teacher” (Luehmann, 2007, p.827). Physics teacher identity is related to teachers’ physics content knowledge and pedagogical knowledge (Avraamidou, 2014). However, beginning preservice physics teachers often have a poor understanding of physics concepts and difficulties with solving physics problems (Davis et al., 2006; Aviyanti, 2020). This raises a challenge for physics courses, given that conceptual understanding plays a key role in physics teachers’ learning and development (Azam, 2018). This is especially the case for Indonesian universities, at which, commonly, physics lecturers use traditional teaching methods stimulating plug-and-chug approaches in problem-solving (Aviyanti, 2020).

More recently, researchers examined how the use of multiple representations (MR) in physics teaching might impact student learning and provided evidence of the potential of the use of MR in supporting the development of both conceptual understanding and scientific skills (Munfaridah et al., 2021). As Mathewson (1999) argued, one of the most crucial ways of using scientific creativity and communicating scientific ideas is by means of visual representations, which also play an important role in teaching physics. Moreover, Hill and Sharma (2015) emphasized that using representations, such as words, graphs, equations and diagrams, is important to succeed in scientific disciplines.

In reviewing the literature on MR in physics education, it becomes clear that the use of MR contributes to students’ conceptual understanding (Munfaridah et al., 2021), and, probably, to their physics identity and physics teacher identity. When discussing the role of MR in physics teaching and learning, Opfermann et al. (2017) pointed out that MR have a great potential in supporting students’ learning of physics concepts, because: (a) many kinds of representations can be used in representing phenomena and concepts in physics; (b) students can choose representations based on their learning preferences; and (c) many concepts, processes, or relations can be comprehended faster when employing different representations. Savinainen et al. (2017) found a positive correlation between students’ understanding of representations and their learning gains in physics. Even though these researchers were not able to determine a causal correlation between MR and students’ learning of Newton’s third law, they argued that the use of MR in the learning process influenced students’ understanding of physics concepts.

In this study we use the MR-based instructional approach, which refers to a learning process applying different representations and where students construct evidence-based claims, critique and modify representations and then refine both initial claims and representations (Sutopo & Waldrip, 2014). We expect to influence preservice physics teachers’ development of physics identity and physics teacher identity through the implementation of this approach in an introductory physics course on thermodynamics in an Indonesian university. In the following sections, we will discuss the relationship between the MR-based instructional approach and physics identity and physics teacher identity, and the design and implementation of this approach in the introductory physics course.

The Role of MR on Physics Identity Development

We argue that physics identity components are directly related to the use of MR by stimulating students’ conceptual understanding and problem-solving skills. Previous studies showed that students’ conceptual understanding showed great improvement by employing an MR approach in high school physics (Savinainen et al., 2017), and in introductory courses for undergraduate students (Munfaridah et al., 2021; Susac et al., 2019; Sutopo & Waldrip, 2014) compared with traditional courses in physics. As pointed out by Ainsworth (1999), one of the functions of MR is providing students with deep conceptual understanding. Another finding from the literature is that students realized that they obtained better problem-solving skills after learning with MR (De Cock, 2012; Kohl & Finkelstein, 2006). Wang et al. (2018) found that problem-solving activities in high school might help students in maintaining their physics identity to face future experiences with physics. Thus, employing the MR approach in physics learning can help students to improve their competence, which directs the construction of students’ physics identity.

According to Hazari et al. (2010), physics identity has four main components: competence, performance, interest, and recognition. In this framework competence refers to belief in understanding physics concepts. As proposed by Carlone and Johnson (2007) in their science identity model, competence refers to being proficient in practices that are relevant in a particular context, for instance, physics learning. We agree with Carlone and Johnson that it is not enough if we only know students' perception of competence. Deslauriers et al. (2019) found that students in an active classroom learn more, but they feel like they learned less. This showed that students' perceptions of their learning do not always correspond with their actual learning. Therefore, we need to determine students' actual competence. Performance is another component of physics identity that might be affected through engagement with the MR-based instructional approach. Performance includes how the person demonstrates the competence to others.

Students' interest is raised by pedagogic techniques aimed at promoting students' visualization skills (Gilbert, 2010), stimulating the integration of verbal and visual representations. Similarly, in the MR approach, students have opportunities to use different representations complementing each other (Ainsworth, 1999). The instructor can elicit preservice physics teachers' explanations in order to support their autonomy and interest. In our approach, preservice physics teachers will engage in many activities such as hands-on activities, watching demonstrations, using equations, and analyzing visual representations (e.g., pictures, diagrams, graphs). In line with the findings from Swarat et al. (2012), the involvement of hands-on activity affects students' interest in science. Other researchers argued that the use of questions, representations in graphs and tables correlates with interest and recognition (Lock et al., 2015). Some researchers reported that MR involved the use of both static pictures and words (De Cock, 2012), dynamic pictures (animation), videos, and applications with digital technology (Zacharia & de Jong, 2014). In a study carried out in chemistry, it has been reported that digital visualizations such as video clips and animations increase students' interest and promote their meaning-making (Patron et al., 2017). Confirming that result, Swarat et al. (2012) reported that the use of technology is an effective way to enhance students' interest in science. Summarizing this, it is expected that the participation of preservice physics teachers in an introductory physics course, which is taught with the MR-based instructional approach, can foster their interest in learning physics. However, we should be aware that employing this approach can also generate difficulties among students, such as when the students are asked to translate from one representation to other representations (Bollen et al., 2017) with a negative effect on their interest. In addition, we need to consider that many students in physics think that physics is identical to mathematical representations such as formulas (Due, 2014). So, their interest might decrease when they get involved in activities without direct use of mathematics.

According to Hazari and Cass (2018), recognition can be stimulated by providing challenging problems. It is common to believe that according to the norms in physics, being good in physics is indicated as a good physics problem solver (Danielsson, 2014). As argued by De Cock (2012), a good physics problem solver should be able to take the benefit of using different representations in physics problem-solving. The preservice physics teachers in this study should accommodate the representations that they are used to, and learn to use other representations. Some students might feel that they have difficulty with this situation. By this, learning with MR can provide a challenging experience for the students, which will end up in the feeling of being recognized in physics learning when they complete this challenge successfully. More interactions in the classroom provide opportunities to create a student-centered learning approach, and more opportunities for teachers to recognize their students (Hazari & Cass, 2018). Students feel recognized because they are more engaged in discussions, not only with their teacher but also with their peers. Jackson and Seiler (2017) found that the dominant teacher-centered approach severely hinders students' opportunities to engage in successful identity work in their courses, especially for the late-comers. In the traditional lecture format, the students are mostly passive and do not have much time for work that contributes to their construction of their science identities.

The Role of MR on Physics Teacher Identity Development

Teacher identity is defined as how the person is recognized as a certain kind of teacher by her/himself and others (Luehmann, 2007). We argue that teacher identity is related with conceptual understanding and problem-solving skills of the person. Teacher identity as integration of knowledge with perceptions, emotions, and knowledge of the world and the self is represented by the Dynamic System Model of Role Identity (DSMRI) (Kaplan & Garner, 2017). This framework has four main components: *self-perceptions and definitions*, *purpose and goals*, *epistemological and ontological beliefs*, and *perceived actions and possibilities*. When the preservice physics teachers are capable in physics, we believe that this will influence the components of the DSMRI, which are the manifestations of their physics teacher identity.

Preservice physics teachers have viewed themselves as future physics teachers since they enter the education program. Through an introductory course, they started developing their knowledge and understanding of physics concepts. The learning experiences with our MR-approach will contribute to the change of preservice physics teachers' competence in physics and support their confidence in teaching physics concepts. Thus, this will also influence the preservice physics teachers' perceptions of the four DSMRI components. The introductory physics course, which is intended to strengthen the subject knowledge of preservice physics teachers, might impact each component of the framework. Strengthening physics knowledge may influence the components of the DSMRI: (a) examples of physics applications will change students' views on physics in society and daily life (epistemological and ontological beliefs); (b) teaching strategies in the course shape students' pedagogical knowledge and future career perspectives (purpose and goals); (c) the use of multiple representations will broaden students' repertoire of teaching strategies (perceived actions and possibilities); and (d) conceptual understanding will develop students' confidence as a teacher (self-perceptions and self-definitions).

Stiles-Clarke and Macleod (2016) showed that having enough interest, having positive learning experiences, and having a positive view about the application of their degree in their career contribute to the physics identity of first-year undergraduate students. Students in our course will see how the MR-based instructional approach will not only increase their understanding of physics concepts but also stimulate their interest in physics. The common view that physics is always something with mathematics and equations will be gradually reduced. The more the instructor emphasizes the use of representations, the more understanding preservice physics teachers will have of how physics problems can be presented and solved. This awareness is expected to be transferred by preservice physics teachers to their future students so that preservice physics teachers can function as an agent in emerging students' physics identities (Chung-Parsons & Bailey, 2019). In the following sections, we describe the design and share examples of preservice physics teachers' (i.e., students from now on) responses from the implementation of this approach.

The Design of the MR-Based Instructional Approach in Thermodynamics

The Introductory Physics Course

The MR-based instructional approach was implemented in the introductory physics course in the first year of the teacher education program. In the curriculum of the teacher education program, this course is aimed to equip students with physics content knowledge, which they will use to teach high school students in the future. The first and second year of this program are focused on the acquisition of physics content knowledge, and the third and fourth year are focused on pedagogical content knowledge and school apprenticeship. Before entering this program, the students already acquired physics knowledge in high school. They started learning physics from junior high school combined with other science subjects (like biology), while in senior high school physics was taught as a separate subject.

The introductory physics course is compulsory and aims to provide students with a comprehensive understanding of theoretical concepts and basic principles of classical and modern physics and its application to relevant problems (see Appendix B). Students are expected to master the body of knowledge of physics in relation of the given physics topics and they are able to scientifically explain natural phenomena and technological products in everyday life (Department of Physics, 2020). The course covers the following physics topics sequentially: fluids, oscillations and waves, thermodynamics, and optics. Before taking this course, students finished another introductory physics course, in which one of the topics is mechanics. Hence, we expected the students already had knowledge regarding the concept of work that will be used in thermodynamics. In this paper, we describe the design and implementation of MR-based instruction specifically in thermodynamics.

Regarding the specific topic in this paper, thermodynamics, the course was designed to help students understand the relationship between the equation of state for an ideal gas, and the first and second laws of thermodynamics. Students learn that state variables will merely change when there is an energy change of the system through either heat (Q) or work (W). In the analysis of thermodynamics processes, students practice using different representations, such as PV-diagrams (to represent the process), mathematical representations (the first law and the ideal gas law), and verbal descriptions to discuss the plausibility of the analysis. Therefore, students are expected to be able to represent various processes in an ideal gas through diagram representations and analyze thermodynamic processes using PV-diagrams in relation to thermodynamics laws.

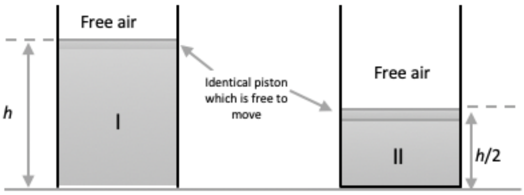
Problems in Multiple Representations

The introductory physics course in the program that served as the context of this study was redesigned recently to incorporate the use of everyday-life examples and MR (i.e., use of pictures, diagrams, equations, verbal reasoning, demonstrations, videos). As defined by Sutopo and Waldrip (2014), the MR-based instructional approach refers to a learning process where students construct evidence-based claims, critique and modify representations and then refine both initial claims and representations. The MR-based instructional approach has general outlines to guide the students' learning processes. At the beginning of the learning process, the instructor presents the problem using some representations. For each representation, the instructor guides students to follow general steps. First, the instructor asks students to identify known variables from the presented problems. This step aims to stimulate students' initial ideas about their claims based on information provided in the representations. Second, the instructor asks students to construct representations, such as diagrams, pictures, equations, and verbal descriptions through collaborative work in a group of two or three students while the instructor moves around the groups and provides assistance according to the written responses of the students. During this step, students are expected to be critical in order to have a rich discussion. The last step is that they share their work with others through a whole-class discussion. The instructor facilitates the discussion to incorporate students' responses. Through this last step, students have an opportunity to correct their work and refine their claims and representations that have been made in the previous steps. Figure 3.5 shows how these steps of this approach can be described, specifically, when the students solved the problem presented in diagram representation (Figure 3.4). In Figure 3.5 we see that the activities can be done both individually and through group work and classroom discussion. Those activities emerged through the instructor's persistence and encouragement in using representations during the learning process. With the incorporation of this approach in the course, we intended that students could solve the problem using coherent representations. It is intended that it will enhance their conceptual understanding and problem-solving skills, which, as we have argued, will contribute to students' identity development.

In what follows, we offer a set of problems as examples and discuss the problem-solving processes for each of the problems. We provided these problems sequentially, based on the topics in the course. We chose these problems to clearly express how the instructor emphasized the use of different representations explicitly. Hence, we can see how the instructor incorporated this approach through the encouragement of students to connect and engage with representations in group work and whole-class discussion.

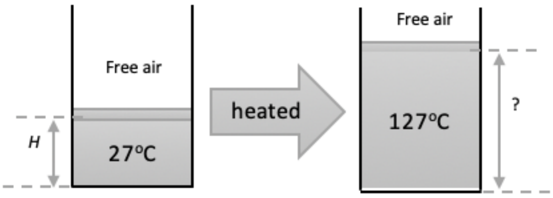
Pictorial Representation

The first example provided here is the problem with a pictorial representation. The problem is about two closed containers, as shown in Figure 1 and Figure 2. These problems were used to introduce the application of concepts of state variables in thermodynamics such as temperature (T), volume (V), and pressure (P). Through these problems, the students were expected to apply the equation of state for an ideal gas: $PV = nRT$ since they were already familiar with this equation.



Two closed containers with the same cross-sectional area contain unknown types and numbers of particles of ideal gases. The identical piston is free to move, and both containers are in contact with free air, as shown below. Determine the ratios of pressures, volumes, temperatures, and numbers of moles in the two containers.

Figure 1. Example problem: using pictorial representations with two containers filled with ideal gases



One closed container contains an unknown amount of ideal gas. The identical piston is free to move, and both containers are in contact with free air, as shown below. Determine the ratios of pressures, volumes, temperatures, and numbers of moles in the two containers.

Figure 2. Example problem: using pictorial representations with a container with a heated ideal gas

In order to solve this problem, the students should understand the initial condition related to the pressure and volume of ideal gases in two containers, both for Figure 1 and Figure 2. All ideal gases in the containers have the same pressure because they are in contact with free air. The volumes are different because, as illustrated in the picture, the heights are different. Before students started to solve the problem, the instructor asked some questions to guide students to understand the initial conditions for these two problems. We provide a fragment of the discussion between the instructor and some students in the class:

Instructor : Look at the Figure 1, based on your observation, what do you think about these following thermodynamics variables (P, V, T)?" "what can you know first from the picture?

Student 1 : The volumes are different

Instructor : How do you know that the volumes are different?

Student 1 : We can see that the ideal gases in the two containers are different, it shows that they have different volume

Instructor : Alright, what about the pressure (P)?

Student 2 : The pressure in the two containers is different, I guess container II has higher pressure than container I because the position of the piston II is lower than piston I.

Instructor : Does anybody have different answer? (with the tone indicating that the answer is not what he expected because it is not the correct answer)

Student 3 : I have the feeling that the previous answer was not correct, but I don't know the correct one; is the pressure of ideal gas in both containers the same?

Instructor : Let's go back to the concept of pressure; given that pressure is the ratio of force and area, do you have any clues based on this concept?

Student 3 : Hmmm,, who is the one that puts pressure on this problem? It is the ideal gas, right?
Instructor : Yeah,, what else? Don’t you notice that there is an equilibrium condition between the pressure of the ideal gas and also the free air?
Student 3 : Ah.. so the pressure of the ideal gas is the same as the pressure given by the free air” (showing the expression that he did not expect such answer)
Instructor : Yes,, that’s correct,,

From the excerpt above, we can see that students had a misunderstanding on the pressure of the gases in Figure 1. However, this misunderstanding was clarified during the discussion with the instructor and other peers. Since they had a clarification for this issue, they applied this concept to the second problem in Figure 2. This made the problem solving for the second problem easier than the first one since the students responded correctly and faster than the previous problem.

After the discussion at the beginning of presenting the problems, students started solving the problem using mathematical representations (i.e., the equation of state for an ideal gas) to find the ratio of each variable in the problems. For example, to find the ratio of volumes of the two gases in Figure 1, students used these mathematical representations:

$$\frac{V_1}{V_2} = \frac{Ah}{A\frac{h}{2}} \text{ and } \frac{V_1}{V_2} = \frac{2}{1} \qquad (1)$$

Since the instructor presented problems in two different conditions as we can see in Figure 1 and Figure 2, students should notice that the number of moles of the gases in the containers in Figure 1 are not given. While, in Figure 2, the amount of the gas is the same. For the problem presented in Figure 1, students cannot exactly determine the ratios of temperatures of the gas in the two containers when using the gas law:

$$T_1 = \frac{PV_1}{n_1 R} \text{ and } T_2 = \frac{PV_2}{n_2 R} \qquad (2)$$

During problem solving, the students had discussions with the instructor and with their peers in groups of two or three. When they had difficulties and got stuck, they asked the instructor for a hint. After students found the mathematical representations, the instructor discussed the solutions in the whole class. Some students voluntarily presented their work and started the discussion. In the end, the instructor confirmed whether the presented solutions were appropriate or not.

The examples above illustrate how pictorial representations supported the explanation of verbal descriptions. When the instructor provided only the verbal descriptions, students might have difficulties imagining the condition of the two containers. Here, it is shown that one of the roles of using representations is a complementary role, given that using texts and pictures together will complement each other (Ainsworth, 2008).

Demonstration

In order to provide a description of how the instructor emphasized the use of representations, we show an example of demonstrations the instructor conducted. Through these demonstrations, the instructor aimed to engage students in observing physics phenomena related to the concepts of pressure (P), volume (V), and temperature (T). This example also serves as a way preservice physics teacher might introduce gas-related concepts in their future classrooms. The demonstrations presented by the instructor were in two different formats, as a live demonstration (Figure 3a) and as a pre-recorded video demonstration (Figure 3b). In Figure 3a, the instructor demonstrates how the pressure changes in a syringe under two conditions. When the tip of the syringe was closed, the plunger was pushed to the initial position after the instructor released the plunger. For the second condition, when the tip was opened, the plunger stayed in the position where the instructor pulled the plunger. During these demonstrations, students observed the activity and answered questions, such as: why is the syringe’s plunger going back into the initial position when it was released? Some students responded to the instructor’s questions. The instructor asked students to verbally explain their responses and make a drawing showing the direction of the force exerted on the syringe. At the end of the discussion with a series of questions and answers from students, the instructor gave his explanation and showed equations to describe this phenomenon.

In Figure 3b, the instructor presents a video demonstrating a blown balloon placed on an Erlenmeyer flask. This video was presented to show a physics phenomenon that involved the relationship between temperature and pressure. In the video, the person struck a match and put it inside the Erlenmeyer flask. After waiting until the flame goes out, the person placed the balloon on the Erlenmeyer flask as shown in Figure 3b. In this part, the instructor facilitates students by giving some clues on what physics variables must be considered in the phenomena. Then, the instructor asked the question, "What will happen next?" providing some possible answers: (a) the balloon will lift up (i.e., the balloon will float above the Erlenmeyer flask); (b) the balloon will be sucked into the Erlenmeyer flask; (c) the balloon will remain the same like before (i.e., the balloon can be moved up easily from the Erlenmeyer flask); and (d) the balloon will burst.

Figure 3. Examples of activities including classroom demonstration (a) and video (b) showing different representations

Before students found the correct answer, most of them answered that the balloon would float above the Erlenmeyer flask. It showed that the students might think that the heating process on the gas inside the Erlenmeyer flask made the pressure higher than outside and then pushed the blown balloon up. We could see that the students responded to the instructor's question slowly and only one student responded confidently that the pressure was decreasing. This is shown in the following fragment of the discussion in the class.

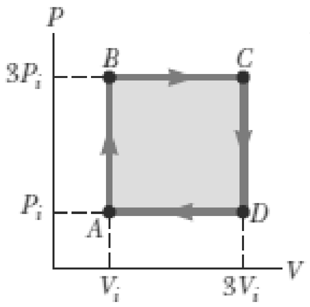
Instructor : After observing the demonstration in the video, what will happen next with the balloon?
Student 1 : It seems that the balloon will lift up (option a) (the students discussed with her peer and showed the movement of balloon that float above the Erlenmeyer flask)
Instructor : Alright, try to think which thermodynamics variables were changed in this phenomenon. What has not changed in the phenomenon when the Erlenmeyer flask was closed with the balloon after the flames went out?
Student 2 : Volume
Instructor : Okay, what about the temperature? Does it change? (the students continue the discussion with others)
Student 2 : Yes, it changed and would adjust to the room temperature
Instructor : Now, try to apply the equation for an ideal gas $PV = nRT$ with this situation
Students : Try to figure out the application of the equation for an ideal gas for this phenomenon.
Instructor : You will find that the balloon was sucked in the Erlenmeyer flask because the pressure in the inside of the Erlenmeyer flask was decreasing and made it lower than the pressure outside. It happened because there are changes in the temperature (decreasing) in the constant volume.

What actually happened was the opposite, namely that the balloon was sucked into the Erlenmeyer flask. The reason was that the pressure inside the flask was decreasing and it was lower than the pressure outside of the Erlenmeyer flask. When the instructor struck a match and put it in the Erlenmeyer flask, the oxygen was removed from the gas in the flask and the gas was at a higher temperature than before. After the flame went out and the Erlenmeyer flask was closed with the balloon, the temperature decreased and it caused the decreasing of the pressure inside the Erlenmeyer flask. In their explanations, students could use both verbal explanations and mathematical representations, like the equation for an ideal gas $PV = nRT$. The demonstrations above, either live or pre-recorded, show the use of various representations to visualize physics phenomena in relation to thermodynamics quantities such as volume, pressure, and temperature.

Graphical Representation

The instructor provided a problem in graphical representation, as a PV-diagram, to be discussed at the beginning of a lesson, as shown in Figure 4. The intention of using this problem was to engage students with the application of the first law of thermodynamics for each of the steps in the cyclic process by explicitly using various representations such as the diagram, mathematical expressions, and verbal explanations. Following that, the instructor showed how this phenomenon could be described in mathematical and diagram representations. After the students understood how the state variables such as volume, temperature and pressure change, the instructor asked the students to solve the problem. Before that, the instructor explained the first law and the concepts of system and environment, internal energy, heat, and work. The learning activities involving the use of MR of this specific problem are presented in Figure 5. The students had a group discussion and described how they applied concepts of the first law using coherent MR. They needed to generate and identify known variables in the given PV-diagram of a cyclic process. Following that, they had to draw arrows representing the energy transfer as heat or work during each step as shown in Figure 6, and constructed verbal descriptions about the process of energy transfer. The next step is formulating an equation for the temperature at each point in the diagram through the ideal gas law $PV = nRT$, and formulating work and heat. At the same time, the students constructed a verbal description of how they applied the first law.

The goal of this activity was to support students in understanding the use of the first law $\Delta U = Q + W$. To use that equation, students needed to understand how the work is defined as the positive work done *on* the system for the process of compression and the negative work done *by* the system for the process of expansion. The students applied the first law of thermodynamics for the whole process. In the end, students evaluated the use of MR regarding the conceptual explanation of the first law of thermodynamics, such as "the total change of internal energy of the system is zero" for the whole cycle. Through this approach, students were expected to be supported in developing an understanding of the application of the first law using coherent representations (Figure 5).



1 mole of monatomic gas undergoes a cyclic process as shown in the figure.

a. Determine the amount of work done by the gas on the environment for each step of the cyclic process. Determine the amount of heat exchanged with the environment for each step of the cyclic process. Also, explain the direction of heat and work.
b. Determine the amounts of heat and work for the whole cyclic process.
c. Determine the energy change for the whole process

Figure 4. The example problem: PV diagram of cyclic process (Adapted from Serway et al. (2014))

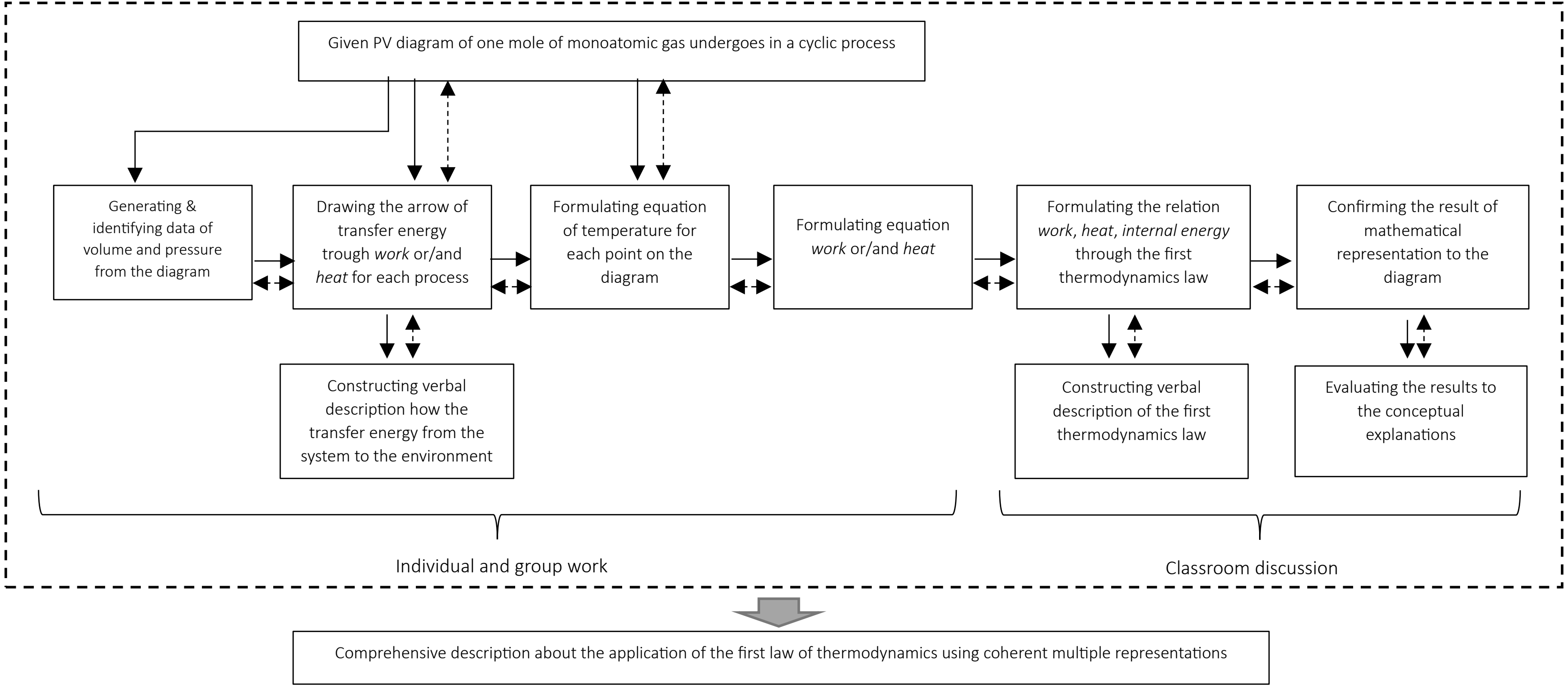


Figure 5. The representational work in problem-solving process of PV-diagram in cyclic process and the first law of thermodynamics. A solid arrow indicates a typical working sequence; a two-headed dashed arrow indicates the activity to check the consistency the use of representations

A brief solution to the problem of the cyclic process is given by the following descriptions.

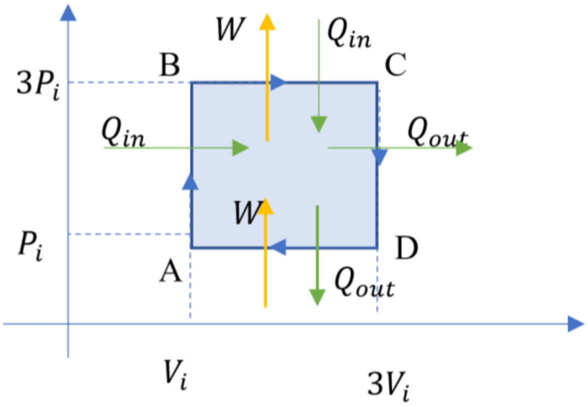


Figure 6. The diagram that represents the energy transfer in the form of heat and work

a. Using the gas law: $PV = nRT$, the students determined the temperature of each point in the diagram as follows:

$$T_A = \frac{P_iV_i}{nR};\ T_B = \frac{3P_iV_i}{nR}\ ;\ T_C = \frac{9P_iV_i}{nR}\ ;\ T_D = \frac{3P_iV_i}{nR} \quad (3)$$

b. Each process step described in the diagram was analyzed based on the changes of variables represented in the diagram. The students determined the direction for heat and work for each step in the process with arrows (Figure 6). At the same time, students created verbal descriptions to explain each step represented by the arrows in the diagram. Next, students calculated the value of work for each step using the equation $W = -P\Delta V$. In addition, students could also calculate the value of total work directly from the diagram (i.e., the area under the line in the diagram). It showed that the PV-diagram could be used to confirm whether the results from mathematical representations were correct or not. Furthermore, for each step of this problem, students determined heat and work. At the end of the problem, students were expected to be able to confirm that the value of the change of internal energy in the cyclic process is zero. Following that, they could also find that the values of heat and work are the same for the total process. It also could be confirmed through the diagram they made for this process where the difference of the area under BC and AD represents the total of work for the whole cycle (i.e., the square area ABCD in Figure 6).

During this phase, the students create their own representations based on directions presented by the instructor. They are free to choose what kind of representations they want to use. They write their answers in their own book or on the whiteboard to make the discussion process easier. Most of the students used written explanations and mathematical representations. In a problem about gas expansion (not shown), the students drew the container with the position of the piston to visualize the problems and gave written explanations in their responses. They also used equations that relate to the given problems. Also, in this stage, they have the opportunity to discuss with peers to find the solution (Figure 7). The instructor observed the discussions and helped students when they had difficulties.

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Figure 7. Peer discussion

Whole-Class Discussion and Clarification

In the last phase, students discussed their responses in front of the classroom. Some of them volunteered and wrote their responses on the whiteboard, while other students compared their answers with the one on the whiteboard, as we can see in Figure 8. Following that, a volunteer explained the answers. Sometimes, the answers of the volunteer and other students were different. This facilitated an engaging discussion among the students. The instructor played a role as the facilitator throughout the entire discussion. Through this stage, the instructor showed that he recognized the students' solutions. From this activity, the students gained more confidence and courage in presenting their arguments. At the end of the learning process, the instructor provided explanations to clarify the concepts that had been misunderstood and gave a brief conclusion.

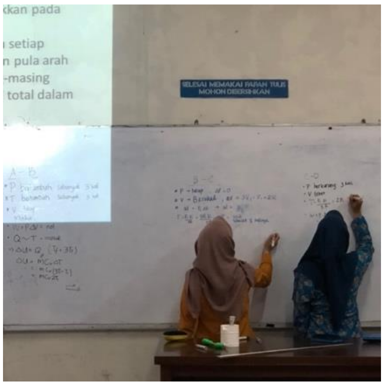

Figure 8. Preservice physics teachers write their responses to the given problem

Our description of the implementation of this approach in the introductory physics course showed how the students were engaged in many activities, such as hands-on activities, observing demonstrations, using equations, and analyzing visual representations (e.g., pictures, diagrams, graphs). Through these kinds of activities, the students created an overview of the phenomena, not only in verbal descriptions but also in other representations. From the literature, it has been reported that the involvement of these activities affects students' interest in science (Swarat et al., 2012), which, we argue, will influence students' identity development. Also, we can see that the implementation of this approach has the potential to facilitate students' individual learning needs and preferences and students' active engagement, as has been argued by Waldrip and Prain (2013). Therefore, the way teachers engage with the students in the class can moderate students' physics identity (Hazari et al., 2015). In addition, such engagement and learning experiences potentially contribute to preservice physics teachers' knowledge, both content knowledge and pedagogical knowledge, because their interest was influenced as well as their conceptualization of themselves as future physics teachers, which is the indication of their physics teacher identity.

Conclusions and Implications

In the implementation of this approach, we realized that we faced some situations that did not match our expectations. Therefore, we reflect on the implementation of this approach and what must be considered when other physics educators want to implement this approach in a physics classroom.

As we have mentioned in this paper, many physics educators already use different representations in the physics class. However, they do not always use representations in the way we have described in this paper. Instructors should be aware of the students' responses when they use this approach in the class. From our experience in implementing this approach, in the beginning, students were interested when the physics concepts were presented with mathematical representations. This situation is in line with the study from Due (2014) that students mostly learn using mathematical representation in physics. When the instructor emphasized the use of other representations, the students tended not to use them. They preferred to maintain using mathematical representations. Through the demonstrations and videos as other forms of representations, we observed that preservice physics teachers started to become interested and realized that physics could be more interesting when it was presented not only with equations. As argued by Swarat et al. (2012), hands-on activities can stimulate students' interest in learning science.

In the beginning, we expected that students would be more active in class. However, only a few students participated actively in responding to the instructor's questions. We assumed that this was caused by the fear of giving wrong answers, which is typical for the cultural context in which the study took place. This condition is in accordance with the findings from Loh and Teo (2017) Asian students including Indonesian students tend to be passive because there is a culture that refers to a high hierarchy between students and teachers. We suggest physics educators to approach their students in ways that support them in enhancing their self-confidence, as, for example, providing clues and guidance in order to participate actively in the class. In addition, the instructor should create a good relationship with the students in the class, thus creating a positive atmosphere. By this, students may feel more recognized, which is one of the important aspects in preservice physics teachers' identity development. As reported by Wang and Hazari (2018), the recognition by the teacher is indicated by the attainability of success that convinces students of their capabilities. In addition, we believe that strengthening the confidence of the students about their capability in physics will exert influence on the students' identity, both physics identity and physics teacher identity.

In this paper, we presented the design of an introductory physics course using an MR-based instructional approach, which is incorporated in the physics education program. Although we have discussed the application of this approach through this paper, and provided some examples how the students' work, we cannot clearly point out the specific aspects of this approach that may lead to the change of physics identity and physics teacher identity. We expected that the engaging aspects, such as the use of representations, can stimulate students' interest in physics and counter the negative stereotype about physics. We believed that through the application of this approach, we provided preservice physics teachers with a particular learning experience that can contribute to the development of their identity, both physics identity and physics teacher identity, especially by improving their conceptual understanding and solving of physics problems. Since we did not have evidence about the role of specific aspects of the MR-based approach, it is necessary to explore this further in future studies.

References

Ainsworth, S. (1999). The functions of multiple representations. *Computers and Education*, *33*(2–3), 131–152. https://doi.org/10.1016/s0360-1315(99)00029-9

Ainsworth, S. (2008). The educational value of multiple-representations when learning complex scientific concepts. In J. K. Gilbert, M. Reiner, & M. Nakhleh (Eds.), *Visualization: Theory and practice in science education* (pp. 191–208). Dordrecht: Springer. https://doi.org/10.1007/978-1-4020-5267-5_9

Aviyanti, L. (2020). *An investigation into Indonesian pre-service physics teachers' scientific thinking and conceptual understanding of physics* [Doctoral Dissertation, Flinders University]. https://flex.flinders.edu.au/file/a44a1398-06d4-451f-808c-6e1a702e060b/1/AviyantiThesis2020_LibraryCopy.pdf

Avraamidou, L. (2014). Studying science teacher identity: Current insights and future research directions. *Studies in Science Education*, *50*(2), 145–179. https://doi.org/10.1080/03057267.2014.937171

Azam, S. (2018). Physics for teaching high school physics: Views of prospective physics teachers and teacher educators about undergraduate physics study. *Journal of Teacher Education and Educators*, *7*(2), 147–164.

Bollen, L., Van Kampen, P., Baily, C., Kelly, M., & De Cock, M. (2017). Student difficulties regarding symbolic and graphical representations of vector fields. *Physical Review Physics Education Research*, *13*(2), 020109. https://doi.org/10.1103/PhysRevPhysEducRes.13.020109

Carlone, H. B., & Johnson, A. (2007). Understanding the science experiences of successful women of color: Science identity as an analytic lens. *Journal of Research in Science Teaching*, *44*(8), 1187–1218. https://doi.org/10.1002/tea.20237

Chung-Parsons, R., & Bailey, J. M. (2019). The hierarchical (not fluid) nature of preservice secondary science teachers' perceptions of their science teacher identity. *Teaching and Teacher Education*, *78*(1), 39–48. https://doi.org/10.1016/j.tate.2018.11.007

Danielsson, A. T. (2014). In the physics class: University physics students' enactment of class and gender in the context of laboratory work. *Cultural Studies of Science Education*, *9*(2), 477–494. https://doi.org/10.1007/s11422-012-9421-3

Davis, E. A., Petish, D., & Smithey, J. (2006). Challenges new science teachers face. *Review of Educational Research*, *76*(4), 607–651. https://doi.org/10.3102/00346543076004607

De Cock, M. (2012). Representation use and strategy choice in physics problem solving. *Physical Review Special Topics - Physics Education Research*, *8*(2), 020117. https://doi.org/10.1103/PhysRevSTPER.8.020117

Department of Physics. (2020). *Dokumen formal kurikulum program studi sarjana pendidikan fisika Universitas Negeri Malang*. http://fisika.fmipa.um.ac.id/

Deslauriers, L., McCarty, L. S., Miller, K., Callaghan, K., & Kestin, G. (2019). Measuring actual learning versus feeling of learning in response to being actively engaged in the classroom. *Proceedings of the National Academy of Sciences*, 201821936. https://doi.org/10.1073/pnas.1821936116

Due, K. (2014). Who is the competent physics student? A study of students' positions and social interaction in small-group discussions. *Cultural Studies of Science Education*, *9*(2), 441–459. https://doi.org/10.1007/s11422-012-9441-z

Gilbert, J. K. (2010). The role of visual representations in the learning and teaching of science: An introduction. *Asia-Pacific Forum on Science Learning and Teaching*, *11*(1), 1–19.

Hazari, Z., & Cass, C. (2018). Towards meaningful physics recognition: What does this recognition actually look like? *The Physics Teacher*, *56*(7), 442–446. https://doi.org/10.1119/1.5055325

Hazari, Z., Cass, C., & Beattie, C. (2015). Obscuring power structures in the physics classroom: Linking teacher positioning, student engagement, and physics identity development. *Journal of Research in Science Teaching*, *52*(6), 735–762. https://doi.org/10.1002/tea.21214

Hazari, Z., Sonnert, G., Sadler, P. M., & Shanahan, M.-C. (2010). Connecting high school physics experiences, outcome expectations, physics identity, and physics career choice: A gender study. *Journal of Research in Science Teaching*, *47*(8), 978–1003. https://doi.org/10.1002/tea.20363

Hill, M., & Sharma, M. D. (2015). Students' representational fluency at university: A cross-sectional measure of how multiple representations are used by physics students Using the representational fluency survey. *Eurasia Journal of Mathematics, Science and Technology Education*, *11*(6), 1633–1655. https://doi.org/10.12973/eurasia.2015.1427a

Jackson, P. A., & Seiler, G. (2017). Identity work in the college science classroom: The cases of two successful latecomers to science. *Science Education*, *101*(5), 716–740. https://doi.org/10.1002/sce.21290

Kaplan, A., & Garner, J. K. (2017). A complex dynamic systems perspective on identity and its development: The dynamic systems model of role identity. *Developmental Psychology*, *53*(11), 2036–2051. https://doi.org/10.1037/dev0000339

Kohl, P. B., & Finkelstein, N. D. (2006). Effects of representation on students solving physics problems: A fine-grained characterization. *Physical Review Special Topics - Physics Education Research*, *2*(1), 010106. https://doi.org/10.1103/PhysRevSTPER.2.010106

Lock, R. M., Castillo, J., Hazari, Z., & Potvin, G. (2015). Determining strategies that predict physics identity: Emphasizing recognition and interest. In Churukian, Jones, & Ding (Eds.), *Physics Education Research Conference (PERC) July 29-30, 2015, College Park, MD* (pp. 199–202). American Association of Physics Teachers (AAPT). https://doi.org/10.1119/perc.2015.pr.045

Loh, C. Y. R., & Teo, T. C. (2017). Understanding Asian students learning styles, cultural influence and learning strategies. *Journal of Education & Social Policy*, *7*(1), 194–210.

Luehmann, A. L. (2007). Identity development as a lens to science teacher preparation. *Science Education*, *91*(5), 822–839. https://doi.org/10.1002/sce.20209

Mathewson, J. H. (1999). Visual-spatial thinking: An aspect of science overlooked by educators. *Science Education*, *83*(1), 33–54. https://doi.org/10.1002/(SICI)1098-237X(199901)83:1<33::AID-SCE2>3.0.CO;2-Z

Munfaridah, N., Avraamidou, L., & Goedhart, M. (2021). The use of multiple representations in undergraduate physics education: What do we know and where do we go from here? *Eurasia Journal of Mathematics, Science and Technology Education*, *17*(1), em1934. https://doi.org/10.29333/ejmste/9577

Opfermann, M., Schmeck, A., & Fischer, H. E. (2017). Multiple representations in physics and science education – why should we use them? In D. F. Treagust, R. Duit, & H. E. Fischer (Eds.), *Multiple representations in physics education. Models and modeling in science education, vol 10* (pp. 1–22). Springer, Cham. https://doi.org/10.1007/978-3-319-58914-5_1

Patron, E., Wikman, S., Edfors, I., Johansson-Cederblad, B., & Linder, C. (2017). Teachers' reasoning: Classroom visual representational practices in the context of introductory chemical bonding. *Science Education*, *101*(6), 887–906. https://doi.org/10.1002/sce.21298

Potvin, G., & Hazari, Z. (2014). The development and measurement of identity across the physical sciences. In Engelhardt, Churukian, & Jones (Eds.), *Physics Education Research Conference (PERC) July 17-18, 2013, Portland, OR* (pp. 281–284). American Association of Physics Teachers (AAPT). https://doi.org/10.1119/perc.2013.pr.058

Savinainen, A., Mäkynen, A., Nieminen, P., & Viiri, J. (2017). The effect of using a visual representation tool in a teaching-learning sequence for teaching Newton's third law. *Research in Science Education*, *47*(1), 119–135. https://doi.org/10.1007/s11165-015-9492-8

Serway, R. A., Jewett, J. W., & Peroomian, V. (2014). *Physics for scientists and engineers* (9th ed.). Boston: Brooks.

Stiles-Clarke, L., & Macleod, M. E. K. (2016). Choosing to major in physics, or not: Factors affecting undergraduate decision making. *European J of Physics Education*, *7*(1). https://doi.org/10.20308/ejpe.95844

Susac, A., Bubic, A., Planinic, M., Movre, M., & Palmovic, M. (2019). Role of diagrams in problem solving: An evaluation of eye-tracking parameters as a measure of visual attention. *Physical Review Physics Education Research*, *15*(1), 13101. https://doi.org/10.1103/PhysRevPhysEducRes.15.013101

Sutopo, & Waldrip, B. (2014). Impact of a representational approach on students' reasoning and conceptual understanding in learning mechanics. *International Journal of Science and Mathematics Education*, *12*(4), 741–765. https://doi.org/10.1007/s10763-013-9431-y

Swarat, S., Ortony, A., & Revelle, W. (2012). Activity matters: Understanding student interest in school science. *Journal of Research in Science Teaching*, *49*(4), 515–537. https://doi.org/10.1002/tea.21010

Waldrip, B., & Prain, V. (2013). Teachers' initial response to a representational focus. In R. Tytler, V. Prain, P. Hubber, & B. Waldrip (Eds.), *Constructing representations to learn in science* (pp. 15–30). Sense Publishers. https://doi.org/10.1007/978-94-6209-203-7_2

Wang, J., & Hazari, Z. (2018). Promoting high school students' physics identity through explicit and implicit recognition. *Physical Review Physics Education Research*, *14*(2), 020111. https://doi.org/10.1103/PhysRevPhysEducRes.14.020111

Wang, J., Hazari, Z., Cass, C., & Lock, R. (2018). Episodic memories and the longitudinal impact of high school physics on female students' physics identity. *International Journal of Science Education*, *40*(13), 1543–1566. https://doi.org/10.1080/09500693.2018.1486522

Wulff, P., Hazari, Z., Petersen, S., & Neumann, K. (2011). Engaging young women in physics: An intervention to support young women's physics identity development. *Physical Review Physics Education Research*, *14*(2), 020113. https://doi.org/10.1103/PhysRevPhysEducRes.14.020113

Zacharia, Z. C., & de Jong, T. (2014). The effects on students' conceptual understanding of electric circuits of introducing virtual manipulatives within a physical manipulatives-oriented curriculum. *Cognition and Instruction*, *32*(2), 101–158. https://doi.org/10.1080/07370008.2014.887083