Chapter 16
Examining Students' Actions While Experimenting with a Blended Combination of Physical Manipulatives and Virtual Manipulatives in Physics

George Olympiou and Zacharias C. Zacharia

Introduction

The number of studies concerning the use of Virtual Manipulatives (VM) and Physical Manipulatives (PM) in science has been increasing considerably in the last few years (Balamuralithara & Woods, 2009; deJong & Njoo, 1992; Olympiou & Zacharia, 2012; Olympiou, Zacharia, & de Jong, 2013; Zacharia, 2015; Zacharia, Olympiou, & Papaevripidou, 2008). To this end, many researchers have tried to document the value of using VM for the enhancement of students' learning in science, by comparing PM with VM in several domains. The discrepant results of these studies lead to the conclusion that the use of PM differs from the use of VM, because of their differing affordances. Given these differing affordances, many researchers have advocated in favor of combining the use of PM and VM (Jaakkola & Nurmi, 2008; Jaakkola, Nurmi, & Veermans, 2011; Toth, Morrow, & Ludvico, 2009; Winn et al., 2006; Yueh & Sheen, 2009; Zacharia et al., 2008; Zacharia & Constantinou, 2008; Zacharia & Olympiou, 2011), in order to combine the advantageous affordances that both PM and VM carry (Zacharia, 2015). Toward this goal, Olympiou and Zacharia (2012) developed a framework that portrays how PM and VM could be blended on the basis of their affordances for enhancing students' understanding of the subject domain. Several studies, using this particular framework, have shown that blended combinations could be conducive to students' understanding (e.g., Olympiou & Zacharia, 2012; Zacharia & Michael, 2016). However, none of these studies have looked into what differences emerge in discourse and actions that cause this differentiation in favor of the blended combinations of PM and VM, as opposed to PM alone. To this end, we decided to examine whether the use of blended combinations of PM and VM affects students' actions in a different manner than the actions followed by students using only PM.

G. Olympiou (✉) · Z. C. Zacharia
Department of Educational Sciences, University of Cyprus, Nicosia, Cyprus
e-mail: olympiog@ucy.ac.cy

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The purpose of this study was to go beyond the results of the extant comparative studies among PM and VM and combinations of PM and VM and investigate the experimental procedures and actions followed by the students when enacting experimentation with PM or a combination of PM and VM. The idea was to get an insight as to the reasons causing the differences in students' learning when using different manipulatives during experimentation. To this end, we set as our overarching goal the investigation of students' actions, while PM alone and a blended combination of PM and VM are set for experimenting in the physics domain of Light and Color. The blended combination was based upon the framework developed by Olympiou and Zacharia (2012).

Theoretical Background

Experimentation has been a central feature for science learning across several learning theories (e.g., active learning theory, constructivism). The idea is to transfer the scientist-science paradigm within class. For instance, the principles of the active learning theory (learn by doing), which entails students' active involvement in their learning process, are in total alignment with having students design and execute experiments for testing hypotheses or answering research questions. In fact, active learning approaches, such as discovery learning and inquiry-based instruction, involve experimentation in the process of science learning. The inquiry approach, which is the dominant learning approach (besides traditional lecturing) at the moment, portrays experimentation as one of the main ingredients of supporting students' science learning (van Joolingen & Zacharia, 2009).

Experimentation could be enacted through the use of different means (e.g., physical materials and apparatus, simulations, virtual reality, remote labs). For the purposes of this study, we focus only on physical manipulatives (the use of concrete materials and apparatus) and virtual manipulatives (the use of computer simulations with no haptic devices).

PM and VM

The added value of using PM and VM in science laboratory experimentation has been documented by many researchers in the literature, especially for enhancing students' conceptual understanding across several domains (Finkelstein et al., 2005; Henderson, Klemes, & Eshet, 2000; Hofstein & Lunetta, 2004; Hsu & Thomas, 2002; Jaakkola et al., 2011; Toth et al., 2009; Triona & Klahr, 2003; Winn et al., 2006; Zacharia, 2005, 2015; Zacharia & Anderson, 2003; Zacharia & Constantinou, 2008; Zacharia & Olympiou, 2011; Zacharia et al., 2008). Either alone or in combination, all studies showed improvement of students' learning/performance within their condition. However, in the cases where PM, VM, and their combinations were compared, mixed results occurred. In other words, the literature reports instances in which all means of experimentation were found to be more conducive to student learning than the other. At first, these findings appear to be discrepant to each other. However, a more detailed look of the methods followed, and the manipulatives used revealed that the differences emerged due to the differing affordances that PM or VM carry. Overall, the idea coming out of these findings is that the mean of experimentation that carries a unique affordance (i.e., not carried by the other means), which favors the fulfilment of the learning goal at hand, will be the one to surpass the impact of the other means.

In the literature, a number of such PM and VM affordances are reported (e.g., Huppert, Lomask, & Lazarowitz, 2002; Klahr, Triona, & Williams, 2007; Olympiou & Zacharia, 2012; Zacharia, 2015). For example, in the case of PM, physicality (actual and active touch of concrete material) is reported as one unique affordance (see Zacharia, Papaevripidou, & Loizou, 2012). Students' learn how to handle concrete, physical materials and apparatus and develop the relevant tactile skills required for their proper use (Gire et al., 2010). Another PM affordance is that measurement errors are present by nature, whereas in virtual environments measurement errors are often ignored. In other words, through the use of PM, students come to understand the real, "messy" nature of the world and the existence of measurement errors, which need to be considered and dealt with for correcting the data collected through an experiment (Toth et al., 2009).

In the case of VM, a larger number of unique affordances exist than in the case of PM (Ronen & Eliahu, 2000; Smetana & Bell, 2012; Trundle & Bell, 2010). VM were created to complement the insufficiencies of PM experimentation, which resulted in a vast number of VM unique affordances. For example, in VM environments reality parameters could be altered (e.g., accelerate, decelerate, and freeze time), simplified (e.g., remove errors), or be "augmented" (e.g., add vector representations). Moreover, VM allow manipulation of variables which would be impossible to change in the natural world (e.g., remove all trees from planet earth to study the effects on climate), offer immediate feedback in case of errors during setting or executing an experiment and offer scaffolding to support students during experimentation (for more details see Olympiou & Zacharia, 2012).

Blending PM and VM

Given the differing unique affordances of PM and VM, several researchers have argued in favor of blending PM and VM together in order to take advantages of as many unique affordances as possible (Olympiou & Zacharia, 2012; Winn et al., 2006). In fact, Olympiou and Zacharia (2012) developed and tested a framework for blending PM and VM in an attempt to optimize student learning through experimentation. Findings revealed that the framework was successful in enhancing students' performance (e.g., Olympiou & Zacharia, 2012; Zacharia & Michael, 2016). However, no research was conducted for identifying the reason behind the blended combinations' success over PM and VM alone conditions. In general, there is a lack of research in investigating the differences emerging through the use of PM or VM by studying students' discourse and actions. Such research is crucial in order to explain the differences in performance identified in prior research. For instance, are students' actions different when experimenting with a blended combination of PM and VM and PM or VM alone? If yes, in what respect? What are the aspects of students' actions causing the variation in performance?

This Study

This study aimed at investigating the similarities or differences between students' actions, who used either PM alone or a combination of PM with VM (PMVM) for conducting the study's experiments. For coding students' actions while experimenting, we analyzed (a) the kind of activity that is routinely defined by the curriculum material; (b) students' actions across each of the study's experiments by using a particular coding scheme (see Scherr, 2008; Scherr & Hammer, 2009); (c) classroom talk and questions based on a framework describing different types of questions regarding procedures followed during the experimental setup, as well as the scientific content of the study; and (d) the scientific accuracy of students' predictions, observations, and explanations for each of the study's experiments.

The study was contextualized through the *Physics by Inquiry* curriculum (McDermott & The Physics Education Group, 1996) aiming to compare the experimental procedures/actions taking place during undergraduate students' laboratory experimentation in the domain of Light and Color. Two conditions were involved in the study's research design, namely, the PM alone condition and the blended PMVM condition. Blending PM and VM was based upon the Olympiou and Zacharia (2012) framework developed for combining PM with VM, for developing conceptual understanding.

The main purpose of this study was to compare students' actions between the two conditions in order to identify the reasons behind the superiority of the PMVM condition in enhancing students' conceptual understanding than the PM alone condition. We found in a previous research of ours that the PMVM condition had statistically significant higher mean scores than the PM alone condition (Olympiou & Zacharia, 2012). Specifically, we aimed at answering the following research question:

- How do the experimental procedures/actions that students follow differ when the students experiment with PM and a blended combination of PM and VM?

Methods

Sample

The participants of the study were 15 (freshmen) undergraduate students of a university in Cyprus who were enrolled in an introductory physics course that was based upon the Physics by Inquiry curriculum (McDermott & The Physics Education Group, 1996). The sample was drown randomly from a sample of 70 undergraduate students (see Olympiou & Zacharia, 2012). The 15 participants were randomly separated into two conditions, namely, the PM alone condition (seven students) and the PM and VM blended combination condition (PMVM condition; eight students). None of the participants had taken college physics prior to the study. The students in all conditions were randomly assigned to groups (three or four persons in each group) as suggested by the curriculum of the study (McDermott & The Physics Education Group, 1996).

Curriculum Materials

In this study, we used the chapter of Light and Color of the Physics by Inquiry curriculum (McDermott & The Physics Education Group, 1996). The success of the Physics by Inquiry curriculum is grounded on three foundational components that were found to support conceptual understanding, namely, inquiry, socioconstructivism, and the POE (predict-observe-explain) strategy (see Zacharia et al., 2008). For the purposes of this study, we selected two experiments from the section of colored light. Specifically, we selected:

- Experiment 4.1: An introductory experiment, which guides students to conduct several mixtures of colored light, in an attempt to understand how to combine light of different colors to obtain a particular color of light and differentiate colored light from colored paint.
- Experiment 4.4: An experiment introducing the use of color acetates and prisms when mixing colored light in front of a screen.

The two experiments were purposefully selected, because they included all the main procedures and concepts of the content to be learned. Through these experiments, the students were encouraged to develop a mental model that would enable them to predict what the color of an object will be when viewed under the light of different colors or through colored acetates.

Material

Physical Manipulatives

PM involved the use of physical instruments (e.g., rulers), objects (e.g., cubes), and materials (e.g., lamps, torches, different color acetates, projectors) in a conventional physics laboratory. During PM experimentation, feedback was available to the students through the behavior of the actual system (e.g., a colored shape on a screen) and through the instruments that were used to monitor the experimental setup (e.g., rulers, screens).

Virtual Manipulatives

VM involved the use of virtual instruments (e.g., rulers), objects (e.g., cubes), and materials (e.g., lamps, torches, different color filters, projectors) to conduct the study's experiments on a computer. In the case of the PMVM condition, a part of both experiments analyzed was conducted through the virtual laboratory *Optilab* (see Fig. 16.1) (Hatzikraniotis, Bisdikian, Barbas, & Psillos, 2007). Optilab was selected because of the fact that it retained the features and interactions of the domain of Light and Color, as PM did. The software offered feedback throughout the conduct of the experiment by presenting information (e.g., distance, color) through the displays of the software. No feedback was provided by the software during the setup of an experiment.

Despite the fact that PM and VM provided analogous feedback to students, VM carried additional affordances in comparison to PM. For instance, VM (at the PMVM condition) offered feedback on the outcome color (i.e., the name of the

Fig. 16.1 The *Optilab* environment

color) of any experiment that involved combining colored light. Additionally, the VM offered ray diagrams.

Procedure

All participants were introduced to the Physics by Inquiry curriculum by engaging in the treatment of the condition they belonged to. All students in both conditions were familiarized with the material and the instruments that were going to be used (either PM or VM) before the study's treatment and completed all of the Light and Color sections before the one at task.

In general, the procedures followed in both experiments, according to the Physics by Inquiry approach were somewhat the same, namely, (i) students' experimentation with different beams of colored light, colored acetates, and prisms, (ii) categorization of results in primary and secondary colors of light and their behavior under specific circumstances (e.g., under white or green or red color, etc.), and (iii) students' conclusions based on their explanations and discussion of their results with the instructors.

The role of the instructor was critical. It is supportive in nature and requires instructors' engagement in dialogues with the students of a group at particular points of the activity sequence, as specified by the Physics by Inquiry curriculum. Both conditions shared the same instructors. All instructors were previously trained in implementing the Physics by Inquiry curriculum and had experienced its implementation at least for 2 years.

The duration of the whole study was 13 weeks. Although, the two experiments we focused for the purposes of this chapter lasted 2 weeks. All conditions were facilitated in the same laboratory environment that hosts both conventional equipment and a computer network arranged at the periphery. Students met once a week for one and a half hour. The time-on-task was the same for all conditions.

Data Collection

The data collection involved videotaping students' actions and discussions while experimenting in both conditions (PM and PMVM), as well as collecting reflective journals of instructors during the intervention. In the PMVM condition, a screen-captured data software was also used for the purposes of the study. Whole group videotaped conversations were used as the primary data source for this chapter. Previous work was focusing on assessing students' performance through the use of conceptual tests (e.g., Olympiou & Zacharia, 2012; Zacharia & Michael, 2016). Hence, no information was provided in those studies on what type of students' actions or procedures were taking place when students were using blended combinations of PM and VM. Such information is important in order to identify the possible reasons behind students' differences in test performance. For the purposes of this study, we investigated whole group student conversations in the context of experimenting with PM or a blended combination of PM and VM in order to capture students' actions. We also used instructors' reflective journals for enriching our data and for triangulation purposes.

Instructors' Reflective Journals

All instructors kept a reflective journal in which they had to document and reflect upon a group's (a) difficulties when setting up and conducting an experiment, (b) conceptual understanding related problems while conducting an experiment, and (c) level of understanding of colored light concepts per experiment. Finally, the instructors were asked to reflect on any additional actions made by the students, which were not included in the curriculum material.

Video Data

The video data collection involved videotaping two groups of students from each condition, throughout the study. All four groups were randomly selected. In the case of PM, we used two camcorders: one focusing on students' faces for recording their conversations and the other on the lab bench to capture their experiment setups. In the case of VM (PMVM condition), we used one camcorder and a screen capture software. The camcorder was used to videotape students' conversations, and the screen capture plus video-audio software (River Past Screen Recorder Pro) was used to capture their computer work activity.

We intentionally selected and analyzed the aforementioned experiments of the colored light section. These experiments were selected because the students of the two conditions were found to have statistical significant differences in their scores on a conceptual test. Specifically, the PMVM students were found to have higher scores than the PM alone students (Olympiou & Zacharia, 2012). Thus, the idea was to examine whether this difference in test performance could be associated to possible differences in the student actions during the PMVM and PM alone experimentation.

We located the video excerpts of the two specific experiments in both conditions and proceeded with transcribing the corresponding dialogues of students' group work (data collected through camcorder 1) and with coding students' actions (data collected through camcorder 2 or the screen capture software). Our unit of analysis was single-student utterances, each of which was analyzed separately and received only one code. All student conversations were analyzed, corresponding to eight meetings overall (two meetings in each group of each condition).

Data Analysis

The data analysis focused on identifying patterns in the verbal exchanges of the learners from the ground up, as well as patterns in their actions during experimentation. We developed a coding scheme for coding both utterances and experimentation procedures carried out by students, as well as the students' interactions with the instructors in each condition, applied either by students or instructors or by the curriculum material.

For the development of the coding scheme used for this purpose, we first identified similar studies in which students' group work in science was analyzed, based on specific coding schemes. Specifically, the coding scheme emerged in this study was based on research studies focusing on students' interaction as well as on instructors' questioning and providing feedback to students in science group activities (see Chin, 2006; Conlin, Gupta, Scherr, & Hammer, 2007; Scherr, 2008; Scherr & Hammer, 2009). At the same time, a conscious effort was made to investigate students' group work in inquiry-based experimentation environments (e.g., Redish & Steinberg, 1999), in order to define the main steps of strategies used in such learning environments, especially the ones based upon the Physics by Inquiry curriculum (e.g., POE strategy). We then run a pilot study videotaping three groups experimenting with the Physics by Inquiry curriculum in the domain of Light and Color (one in each condition, PM and a combination of PMVM), in order to apply the categories of the coding scheme that emerged through the literature. This way, we paid close attention to student talk and the experimental procedures followed in the same

Table 16.1 The students' actions coding scheme

Category	Codes
Who is talking	(a) the students, (b) the instructor
Dialogue components	(a) Questions regarding scientific content, (b) scientifically accepted answers, (c) scientifically not accepted answers, (d) scientifically accepted statements, (e) scientifically not accepted statements, (f) comments about scientific content, (g) reading instructions, (h) irrelevant comments, (i) procedural comments, (j) questions regarding the experimental procedures, (k) scientifically accepted answers regarding the experimental procedure, (l) scientifically not accepted answers regarding the experimental procedure, (m) comments regarding the experimental procedure
Predictions	(a) Scientifically accepted prediction based on previous experiment, (b) scientifically not accepted prediction based on previous experiment, (c) scientifically accepted prediction based on previous knowledge, (d) scientifically not accepted prediction based on previous knowledge
Explanations	(a) Scientifically accepted explanation based on previous experiment, (b) scientifically not accepted explanation based on previous experiment, (c) scientifically accepted explanation based on previous knowledge, (d) scientifically not accepted explanation based on previous knowledge, (e) scientifically accepted explanation based on the experiment at task, (f) scientifically not accepted explanation based on the experiment at task

environment like the one used in this study, without losing the details emerging through the different condition experimentation (PM and PMVM). As per our subcategories, we followed the procedures defined by the experiments selected through the inquiry-based curriculum that was used (Tables 16.1 and 16.2). Using these as our starting points and following the data which emerged through our pilot study, we added new subcategories or refined categories according to the transcribed data collected. The methods used in analyzing students' group work in each experiment tried to capture a viewpoint of both students' work in each group as well as the interactions which emerged through students'-instructors' conversations.

During the completion of our coding scheme, we first acknowledged that dialogues among students contained, apart from questions and answers regarding both context and experimental procedures, statements regarding the context of the studies (scientifically accepted or not) as well as neutral comments regarding the conceptual context of each experiment. Thus, we expanded the category of students' dialogues with the three codes discovered. Finally, the coding scheme involved six categories, with their subcategories presented. Table 16.3 provides an example of the descriptions of one of the six codes, namely, the inquiry cycle category, and short examples of the coded conversation. After finalizing the coding scheme, all coding was carried out by the two authors (Cohen's Kappa 0.88). Differences in the assigned codes were resolved through discussion.

For the purposes of this study after coding students' actions (see Table 16.1), we constructed timeline graphs, following the approach of Schoenfeld (1989). The *x*-axis of the graph displayed time, and the *y*-axis displayed students' actions. Each action corresponded to a different category of the inquiry cycle (e.g., prediction, observation, etc.). The use of these graphs was to identify any possible interrelationships of the codes (students' actions) over time (see Zacharia & de Jong, 2014). Timeline graphs were produced for experiment 4.1 for each group of each condition. The resulting graphs were compared both within and between conditions.

Additionally the analysis of the reflective journals was based on the memos/profile of each group, which was generated during the interventions from the instructors (Patton, 2002). Specifically, the journals were analyzed in terms of identifying the extent and the manner in which students discussed issues related to the main concepts to be addressed at both experiments. This helped us get a fundamental insight into the areas in which each group consider important in constructing its mental model. Additionally, having developed initial insights about each group foci and difficulties, the analysis of the reflective journals included coding of the issues/

Table 16.2 The experimental procedures/actions coding scheme

Category	Codes
Inquiry cycle	(a) Prediction, (b) experimentation, (c) observations, (d) explanations (evaluation of predictions and observations), (e) conclusions [(i) discussion with instructors at check points, (ii) discussion after the intervention of instructors, (iii) discussion with instructors after students' concluding questions]
Type of activity	(a) Completion of worksheets, (b) use of PM, (c) use of VM, (d) discussion of scientific content or experimental setup, (e) irrelevant comments

Table 16.3 The "inquiry cycle" analysis

Subcategory	Subcategory description	Transcribed data
Prediction	Reference to pre-existing knowledge regarding the experiment to be conducted	"Predict what you would see on the screen if you place a green acetate in front of a red and green color light beam." "we would have seen it green and red, right (the result on the screen)?" (*Student 2*, *group B*, *PM*)
Conversation regarding the experimental set up	Conversation regarding the procedural sequence of conducting the experiment	"Here is the room. Change the radiation angle in order to lighten the screen" (*Student 2*, *group A*, *PMVM*)
Direct observation	Collecting data through senses during experimentation	"It's black. If you place green light through red acetate the result is black. If you place red color, you will observe red, you see, its red." (*Student 3*, *group A*, *PMVM*)
Explanation	Constructing explanations and data analysis, based on pre-existing knowledge and conceptions derived through the analysis	"The secondary colors come from the mixture of primary colors (mixtures in paint). Cyan, magenta and yellow are secondary colors in light" (*Student 1*, *group A*, *PM*)
Student-instructor conversation at checkpoints	Discussing the experimental results in each experiment with instructors at the check points of the curriculum material (see physics by inquiry curriculum, McDermott & The Physics Education Group, 1996)	"Which are the secondary colors that emerge through the mixture of the primary colors of light?" (*Instructor*, *group A*, *PM*)
Student-instructor conversation after an instructor's intervention	Discussing the experimental results or the experimental procedures taking place after an instructor's intervention to the experimental procedure (e.g., in difficulties emerge through experimenting with PM or VM)	"There is a difference in conducting this experiment in relation to that experiment" (*Instructor*, *group A*, *PM*)
Student-instructor conversation due to a student's question	Discussing the experimental results or the experimental procedures taking place after a students' question	"Basically we tried to combine two colors and we accidentally left one colored beam working and we observed black, and we cannot explain this" (*Student 1*, *group A*, *PMVM*)
Irrelevant comments	Irrelevant comments regarding the domain under study	"When we finish class, we must talk regarding the exams." (*Student 3*, *group A*, *PM*)

problems raised during experimentation regarding either the experimental setup or the scientific context at hand.

Results

The data analysis revealed that PM and the blended combination of PM and VM elicited different discussions and actions during experimentation. In fact, the analysis showed that student actions appeared to be influenced in specific categories of analysis by the means of experimentation, while in others the curriculum material dominated students' actions and behavior (see Table 16.4).

Inquiry Cycle

The analysis of the category "inquiry cycle" revealed differences among the two conditions in students' actions during both experiments. Specifically, in both experiments analyzed, the blended combination of PMVM was found to have a much higher number of student utterances concerning direct observations during experimentation than PM alone. No differences were found between the two conditions during the analysis in the rest of the subcategories of the "inquiry cycle," in both experiments. The analysis of the reflective journals revealed that PMVM students would combine and compare their direct observations through both means (PM and VM) for the same experiment. Particularly in certain occasions, such as when secondary colors of light were mixed (experiment 4.1), PMVM students felt the need of observing this phenomenon on both VM and PM, despite the fact that the curriculum material instructed them to conduct these observations using only VM. In addition, during their first time of using colored acetates and colored light in experiment 4.1, students who used PM in both conditions confronted difficulties in using the laboratory's equipment according to the curriculum material, which triggered the interventions of the instructors during experimentation (e.g., how to mix green with red light). The PMVM students did not face these problems/issues, which appears to indicate that the presence of VM enabled PMVM students handle these issues on their own.

Who Is Talking

The category of "who is talking" refers both to student-to-student and to instructor-to-student talk and includes all dialogue components (e.g., questions posed, answers or suggestions offered, etc.; see the coding scheme in Table 16.1) regardless of the activity taking place. In terms of who is talking during experimentation, our

Table 16.4 Students' discourse and procedures/actions during PM and PMVM experimentation in experiment 4.1

Discourse and experimental actions	Categories	PM Group A	PM Group B	PMVM Group A	PMVM Group B
Inquiry cycle	Predictions	4	20	5	52
	Experimentation	52	133	139	128
	Observations	120	74	317	400
	Explanations (evaluation of predictions and observations)	102	90	262	101
	Conclusions—Discussion with instructors at checkpoints	87	200	112	91
	Conclusions—Discussion after the intervention of instructors	51	49	18	79
	Conclusions—Discussion with instructors after students' concluding questions	22	30	39	75
	Irrelevant comments	18	171	19	94
Who is talking	Students	369	641	830	921
	Instructors	80	122	81	99
Type of activity	Completion of worksheets	13	16	39	95
	Use of VM	0	0	182	274
	Use of PM	89	85	186	265
	Discussion of scientific content or experimental setup	335	494	485	292
	Irrelevant comments	17	173	19	94
Dialogue components	Scientifically accepted answers	33	39	76	59
	Scientifically not accepted answers	13	21	35	39
	Questions regarding scientific content	63	77	165	139
	Scientifically accepted statements	39	61	132	150
	Scientifically not accepted statements	24	35	66	75
	Comments about scientific content	51	102	92	82
	Reading instructions	9	13	7	10
	Irrelevant comments	34	182	20	95
	Procedural comments	54	106	103	128
	Questions regarding the experimental procedures	41	32	53	77
	Scientifically accepted answers regarding the experimental procedure	20	15	29	30
	Scientifically not accepted answers regarding the experimental procedure	5	3	2	3
	Comments regarding the experimental procedure	63	81	131	133

(continued)

Table 16.4 (continued)

Discourse and experimental actions	Categories	PM Group A	PM Group B	PMVM Group A	PMVM Group B
Predictions	Scientifically accepted prediction based on previous experiment	0	0	3	4
	Scientifically not accepted prediction based on previous experiment	0	7	1	4
	Scientifically accepted prediction based on previous knowledge	0	0	0	0
	Scientifically not accepted prediction based on previous knowledge	0	0	0	4
Explanations	Scientifically accepted explanation based on the experiment at task	25	52	79	54
	Scientifically not accepted explanation based on the experiment at task	14	13	36	21
	Scientifically accepted explanation based on previous experiment	3	13	17	8
	Scientifically not accepted explanation based on previous experiment	1	3	10	4
	Scientifically accepted explanation based on previous knowledge	0	0	0	3
	Scientifically not accepted explanation based on previous knowledge	0	0	0	0

analysis revealed different results in the two experiments. Specifically, PMVM students were found to talk comparatively longer than their PM counterparts during the experiment 4.1, whereas at the second experiment (4.4), no differences were found. These results are deeply connected with the results of the "inquiry cycle" category. Since PMVM students conducted more rounds of experiments and made more direct observations, especially during the experiment 4.1, they spent more time discussing their findings between them and with the instructors. The reflective journals revealed that during experiment 4.1, students were involved in discussions of contrasting their observations taken between PM and VM, something that was not required by the curriculum material. Having done that, PMVM students felt no need of following the same procedure in the experiment 4.4, at least not at the same extent, which led to no differences between the two conditions.

Dialogue Components

Students in PMVM condition elicited nearly a double number of questions concerning the scientific content, in comparison with their counterparts in the PM condition (165 and 139 questions made by the PMVM groups A and B, respectively; 63 and 77 questions made by the PM groups A and B, respectively). Similarly, PMVM students elicited a double number of answers regarding the scientific concepts at task (76 and 59 answers stated by the PMVM groups A and B, respectively; 33 and 39 answers stated by the PM groups A and B, respectively). Additionally, the PMVM students stated approximately three times more scientifically accepted statements than the students in PM condition during experiment 4.1. No such differences emerged between the two conditions during experiment 4.4.

The number of questions regarding the experimental setup of the experiment, as well as the answers given, followed a similar pattern in both experiments, though a slight difference was observed in favor of PMVM students during experiment 4.1 (77 and 53 questions stated by the PMVM groups A and B, respectively; 41 and 32 questions stated by the PM groups A and B, respectively). PMVM students asked more questions on content than students in PM condition during experiment 4.1. They also proceeded in stating more comments when setting up the same experiment. To this end, no differences emerged for experiment 4.4. Moreover, our analysis showed no differences among the two conditions in stating neutral comments on scientific content, in reading instructions from the curriculum material and on irrelevant comments in both experiments. The analysis of experiment 4.4 presented only one difference between the two conditions, specifically in organizing procedural matters during experimentation. The PMVM condition bended on procedural issues during the experiment of absorption of colored light, presenting a double number of student utterances in comparison with the PM condition. This result emerged due to the preparatory work of the two PMVM groups, in writing down a series of tests and measures they later on followed to construct their explanations of how light travels through color acetates. Again, these results are strongly connected with the experimental procedures followed from the students in each condition.

The fact that PMVM students elicited more questions and answers concerning the scientific content as well as more scientifically accepted statements is connected to the fact that students proceeded in their own initiative in discussing the results emerging from both means of experimentation. Though different parts of each experiment were conducted with PM or VM, students had no problem of engaging in more inquiry cycles (using POE strategy), using observations or experimental procedures conducted or applied in PM and VM conditions interchangeably, and in reaching safe conclusions regarding the results of mixing colored light. The fact that most differences were only derived through the analysis of experiment 4.1 may be related to the fact that many of the issues students had during experimentation were addressed, so they confronted no difficulties in using or in engaging in new experimental procedures with PM or VM during experiment 4.4. For instance, PMVM students had already understood the underlying mechanism of the use of color acetates in color light mixtures before they engage in experiment 4.4. Despite the fact that similar results emerged in this experiment with PM students, it was likely that PMVM students had reach to deep understanding of how colored acetates worked before they reach to the aforementioned experiment. Hence PMVM students, having no important issues to address in terms of conceptual understanding of the phenomenon studied (use of colored acetates, analysis of colored light and mixing of colored light) dedicated comparatively more time in organizing all their experimental efforts (specifically colored light combinations with the use of all colored filters at hand), before enacting the experimentation procedures. Students in PM condition did not proceed to this level of organizing their work because they felt at some point like involving in sumptuous procedures when other important understanding issues, like for instance, understanding the mechanism of the phenomenon of absorbing colored light through acetates, were still at hand.

Predictions and Explanations

No significant differentiations emerged through the analysis and comparison of students utterances among the two conditions regarding the conduction of predictions in both experiments. According to the curriculum material, both experiments did not require explicit predictions before experimenting with physical or virtual materials, so students did not proceed with stating a high number of predictions. In terms of constructing explanations, students in all conditions made a conscious effort on constructing their explanations, mainly from data based on experiments conducted through the curriculum material. No differences emerged through the comparison of the two conditions, regarding students' utterances in constructing their explanations. The results of the experiments conducted through the curriculum material supported the procedure of constructing explanations. Our analysis showed that students were based primarily on the results of experiments conducted as well as on previous results of the curriculum material. To this end, the curriculum material dominated the documentation of students' explanations, regardless of the manipulatives used during experimentation. No differences emerged among the two conditions regarding the number of scientific explanations that could be linked or attributed to the means of experimentation of each condition.

Type of Activity in PM and PMVM

In analyzing the type of activity taking place in both conditions, specific patterns emerged which could be attributed to the means of experimentation in each condition. Despite the fact that our analysis elicited differences among the two experiments in both conditions, similar patterns emerged according to the means of experimentation used in each condition. Specifically in experiment 4.1, PMVM students experimented either on PM or VM for a far more significant amount of time than their counterparts working with PM (see Fig. 16.2). During experiment 4.4, students in PMVM used for a great amount of time the virtual laboratory Optilab during experimentation. In both experiments, the use of PM was the least, in terms of time and students' utterances. The time allocated from each condition in the actual use of the means of experimentation (PM or PMVM) is also documented from the results on the "inquiry cycle" category, in which timeline graphs show that

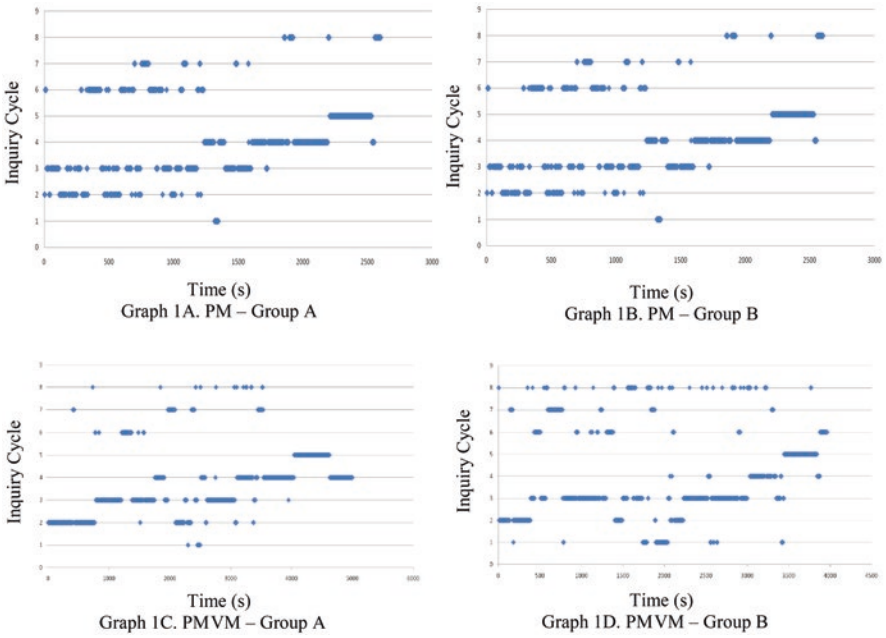

Fig. 16.2 Time graphs of student utterances in the category "inquiry cycle." Graph 1A presents students' actions over time in PM condition (group A of the PM condition) using PM to conduct experiment 4.1 (from part C of the curriculum). Graph 1B presents students' actions over time in PM condition (group B of the PM condition) using PM to conduct experiment 4.1 (from part C of the curriculum). Graph 1C presents students' actions over time in PMVM condition (group A of the PMVM condition) using PMVM to conduct experiment 4.1 (from part C of the curriculum). Graph 1D presents students' actions over time in PMVM condition (group B of the PMVM condition) using PMVM to conduct experiment 4.1 (from part C of the curriculum). The inquiry cycle is analyzed to (1) prediction; (2) experimentation; (3) observations; (4) explanations (evaluation of predictions and observations); (5) conclusions, discussion with instructors at check points; (6) conclusions, discussion after the intervention of instructors; (7) conclusions, discussion with instructors after students' concluding questions; and (8) irrelevant comments

PMVM students during their observations used longer the means of experimentation at hand than their PM counterparts did (see Fig. 16.2).

A slight difference also occurred in completing the worksheets of the curriculum material, among the two conditions in both experiments. Our analysis showed that PMVM students worked on their worksheets longer than PM students did. This result is in line with the increased utterances on discussions that the PMVM condition elicited during experiment 4.4. Specifically, students working with VM at the PMVM condition proceeded in writing down all the combinations of different colors of light travelling through different colored acetates in their worksheets before going forward on conducting the actual experiment. This action was not followed by the PM students, in any of the two groups.

Overall, the PMVM students made a significantly higher number of observations than their counterparts in both experiments, as their utterances prevail in numbers.

Students in the blended combination condition used their means of experimentation more frequently in comparison with the PM condition. This result was mainly profound in the experiment 4.1. Finally, the PMVM students organized the process of mixing colored light in a different manner than PM students, namely, writing and numbering down all their prospective efforts (e.g., colored light mixings).

Discussion and Implications

In the current study, we investigated how students' actions and procedures followed and compared between two conditions, namely, the use of PM alone or the use of a blended combination of PM and VM. In the Olympiou and Zacharia (2012) study, it was found that the blended combination of PM and VM was more conducive to students' conceptual understanding than the use of PM alone. Given this finding, we decided to examine the reasons for causing this differentiation. In so doing, we focused on students' actions, as identified through their actions on videos and as portrayed through their conversations. The idea was to examine whether any variations in actions during experimentation result in different learning outcomes/performance. The findings of this study were particularly revealing in this respect. Specifically, we found in both experiments that the use of PMVM leads students to more rounds of experiments which results in more direct observations (i.e., better data collection/evidence). Students in the blended condition had the chance of using both PM and VM interchangeably, so there were instances in which students after having the opportunity of the real/concrete experience with mixing colored light or light absorption, they could turn to the VM experience to observe in a "more accurate" (i.e., less messier) and quicker manner all different kinds of colored light combinations or absorptions. Such instances occurred more frequently when PM did not offer to students' clear observable outcomes (i.e., due to other light contamination). In the case of PM alone, students spent much time on discussing about these issues, rather than extending their data pool, as it was the case with the PMVM condition. In addition, the fact that in the PMVM condition the data collected were triangulated from two different means of experimentation provided the PMVM students more confidence in terms of the credibility of their findings, which allowed them to have more productive discussions and thus deepen their understanding. On the other hand, the PM alone students were lacking such confidence. As a result, PM students had to struggle to clarify and consent on what color they were observing on the screen.

Students in both conditions expressed similar numbers of prediction and explanation statements. This could be explained by the fact that the curriculum requested from the students to state predictions or explanations at particular parts of the experiments. In other words, given the context of this study, we could not make a claim on whether the means of experimentation affect the number of predictions or explanations stated by the students. Moreover, we cannot make any arguments about their quality (e.g., the scientific accuracy and the degree of deepening of explanations). For the latter, further analysis is needed.

Amazingly, the PMVM students dedicated a significant amount of time in using the means of experimentation for conducting more rounds of the same experiment (with slight alterations every time, e.g., first mix green and blue, then blue and red, etc.) and thus making more observations, instead of proceeding with the rest of the curriculum materials. At the same time, they took the time to fully complete their worksheets by writing down all the possible mixtures of colored light before starting experimentation, hence, not leaving room for missing any combinations. PM students did not follow the same process (they were completing them during experimentation and not following a specific pattern as their counterparts did).

These findings shed light on how VM affordances could be used, along with PM, to maximize instructional or experimental time for deeper conceptual understanding of the domain under study (see Olympiou & Zacharia, 2012) or in organizing better students' group work when experimenting. Moreover, this study showed that the use of different means of experimentation, namely, PM alone or a blended combination of PM and VM, influences aspects of the experimental procedures/actions in a different way. This implies that the selection of the means of experimentation is crucial if we want certain procedures/actions to be in place during experimentation (e.g., going through more observations hence, more inquiry cycles). The same holds true if we aim to establish among students and instructors productive conversations. In this study, it was found that the blended combination was the mode of experimentation that better offered students these opportunities, with VM, along with its affordances, to be the means of experimentation that contributed the most toward this end.

The literature suggests that there is no question whether blended combinations of PM and VM should be used in physics experimentation (e.g., Zacharia & Michael, 2016). The optimization of PM and VM blends may be achieved through efforts similar to the one of this study. By knowing how VM and PM interact with students' actions, we could work toward a better defined and accurate framework on blending PM and VM for optimizing students' learning.

The findings of this study have implications both for researchers and for educators. For researchers, the study points toward a specific research path that needs to be followed in order to unpack the procedures/actions that take place during PM and/or VM experimentation and to better understand their relationship with learning. This study also highlights the essence of selecting means of experimentation. The fact that the means of experimentation might define the number of observations conducted or the level of organizing students' actions in a laboratory could be a fundamental parameter in achieving the prospective learning outcomes in previous efforts of blended combinations of PM and VM. It is of great importance for educators to be informed when to use PM and VM, since it appears that different means of experimentation evoke different procedures/actions during experimentation.

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