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Penulis : Elisabeth Pratidhina, Wipsar Sunu Brams Dwandaru, Heru Kuswanto

No	Perihal	Tanggal
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2.	Bukti konfirmasi review dan hasil review (accepted with minor revision)	14 Juni 2020
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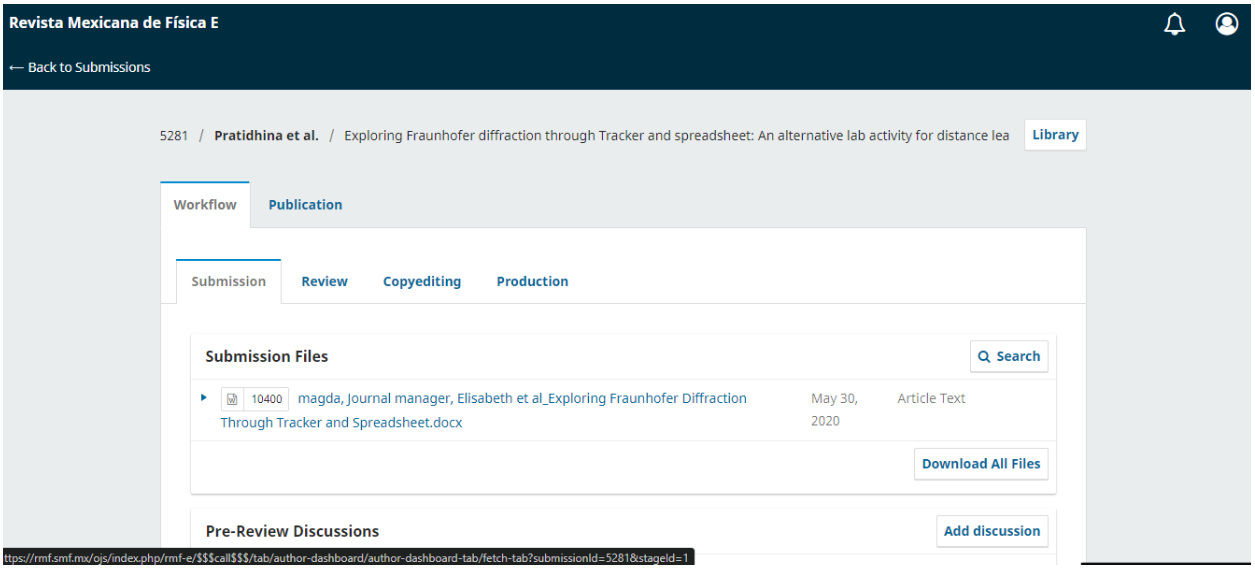
1.	**Bukti submit artikel dan artikel yang disubmit**	**30 Mei 2020**



Bukti Email

Gmail **Elisabeth Founda <elisa.founda@gmail.com>**

[RMF E] Submission Acknowledgement

1 message

Alejandro Ayala <rmf@ciencias.unam.mx> Sat, May 30, 2020 at 11:00 AM
To: Ms Elisabeth FOUNDA Pratidhina <elisa.founda@gmail.com>

Ms Elisabeth FOUNDA Pratidhina:

We hereby acknowledge receipt of your work titled "Exploring Fraunhofer Diffraction Through Tracker and Spreadsheet: An Alternative Lab Activity for Distance Learning". Thank you for submitting the manuscript to Revista Mexicana de Física E.

I would like to point out that with the online journal management system that we are using, you will be able to track your manuscrit progress through the editorial process by logging in to the journal web site:

Manuscript URL: https://rmf.smf.mx/ojs/rmf-e/author/submission/5281
Username: elisafounda

If you have any questions, please contact me. Thank you for considering this journal as a venue for your work.

Alejandro Ayala
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Exploring Fraunhofer Diffraction Through *Tracker* and Spreadsheet: An Alternative Lab Activity for Distance Learning

Elisabeth Pratidhina [1, 2], Wipsar Sunu Brams Dwandaru[1], Heru Kuswanto[1]

[1] Physics Education, Postgraduate Program, Universitas Negeri Yogyakarta

[2]Department of Physics Education, Widya Mandala Catholic University Surabaya

ABSTRACT

In this paper, we present an alternative for physics laboratory activity related to Fraunhofer diffraction in distance learning. The activity utilizes a demonstration video from MIT Open CourseWare, Tracker software, and spreadsheet. An online demonstration video is used because it is the most accessible resource during undesirable conditions such as COVID 19 pandemic. In the activity, students can explore diffractions phenomena with multiple slits. The effect of slit spacing and slit numbers to the intensity of light is investigated trough spectral analysis with Tracker. The investigation is followed by a discussion through the mathematical approach and visualization with spreadsheets. It will enrich students with a theoretical explanation of the observation. This distance learning activity allows students to develop their science process skills, mathematical and computational thinking skills, and conceptual understanding of Fraunhofer diffraction.

Keyword: Fraunhofer diffraction, Tracker, Spreadsheet, Distance Learning

INTRODUCTION

Recently, distance learning and blended learning are being popular. Notably, during the undesirable pandemic, the governments, school principals, and teachers are forced to change traditional classrooms into the digital classes. In a short time, teachers have to think about how to teach their students effectively in distance learning mode. One of the efficient ways is by utilizing the existed resources and technologies.

For physics, the challenge is migrating lab activities from the traditional model to the digital model. Several experiment resources are available online; one of them is *Demonstrations in physical optics* provided by MIT Open Course Ware [1]. The resources include various demonstrations about optical phenomena such as polarization, diffraction, and propagation in optical fiber. That kind of resource can be used to teach physics in distance learning mode. Instead of taking data by hands-on measurement, students can take data by observing the video. Furthermore, to get more in-depth analysis, the video can be analyzed using video-analysis software, such as in *Tracker*.

Tracker is useful free software in physics education, which is developed on the Open Source Physics Java code library. People use it for video analysis and physics modeling. By using *Tracker*, users can track an object's position, velocity, and accelerations [2]. It also has a calibration feature to calibrate the length quantity in the video to the real one. Moreover, the RGB line profile feature in *Tracker* can be used to analyze spectra.

Tracker has been used for pedagogical purposes and complex physics experiments. Educators and scientist use *Tracker* to teach and study various topics such as vector, object falling in liquid and air [3], projectile motion [4], [5], mechanical energy [6], kater pendulum [7], damped harmonic oscillation [8], torsion [9], impulse [10], astronomy [11], and optical geometry [12]. *Tracker* is a potential tool to promote and guide the student as a scientist. Students can explore the laws of nature with *Tracker*. By using video modeling, students can practice to ask questions, use models, and develop mathematical and computational thinking [13]. It also encourages students to think creatively and improve their physics learning performance [14].

Spreadsheets such as *Ms. Excel* are powerful computing and graphical tools. In physics education, we can build simple simulations and visualization in the spreadsheet when we are discussing a physics equation [15], [16].

In this work, we present the use of these two didactic tools, i.e., *Tracker* and spreadsheet, in physics, distance learning activity. We utilize *Tracker* to analyze the Fraunhofer diffraction pattern at double and multiple slits. Instead of record a video from a direct experiment, we use the available demonstration video resources from MIT Open Course Ware. Then, the observed pattern from *Tracker* analysis is compared to the theory by utilizing the spreadsheet program, *Ms. Excel.*

THEORY OF DIFFRACTION

One of the phenomena which can prove the wave nature of light is diffraction. It occurs when a portion of the wavefront is obstructed in some way, and the wavefront is altered in amplitude or phase. Segments of wavefront which propagate beyond the obstacle interfere and construct diffraction pattern [17]. There are two kinds of diffractions, i.e., Fresnel diffraction and Fraunhofer diffractions. In Fraunhofer diffraction, the incoming and outgoing waves approach must be planar over the extent of the obstacles. Fraunhofer diffraction occurs when the distance between the obstacle and the screen is far enough.

The obstacles for Fraunhofer diffraction can be a single slit, double slit, and multiple slits. For Fraunhofer diffraction at N parallel slits, the intensity distribution is given by eq (1).

$$I(\theta) = I_0 \left(\frac{\sin\beta}{\beta}\right)^2 \left(\frac{\sin N\alpha}{\sin\alpha}\right)^2 \qquad (1)$$

With,

$$\alpha \equiv \frac{\pi(b+d)\sin\theta}{\lambda}$$

$$\beta \equiv \frac{\pi d}{\lambda}\sin\theta$$

Where d is the slit width, b is the slit spacing, λ is the wavelength of the light, θ is the observation angle, and I_0 is the intensity of the center maxima, i.e., the intensity in the $\theta = 0$ rad.

METHOD

We use the Fraunhofer diffraction demonstration video available in MIT Open Couse Ware [1]. The diffraction pattern in the video is analyzed by using *Tracker* software. *Tracker* software allows tracking line profiles, which give the data about intensity (luma) at specific points. *Tracker* also allows calibration to match the dimension, such as length, in the video to the real dimension. Fig. 1 shows how the setup of *Tracker* looks like.

After we get the data about point position and intensity in *Tracker*, we bring them to a spreadsheet program to plot the spectra. Then, we plot Eq. (1) with the given parameters in the experiment to provide a theoretical comparison.

In this work, first, we investigate the effect of slit spacing (b) variation on the diffraction spectra at double slits. Second, we investigate the impact of the number of slits variation on the diffraction spectra at multiple slits.

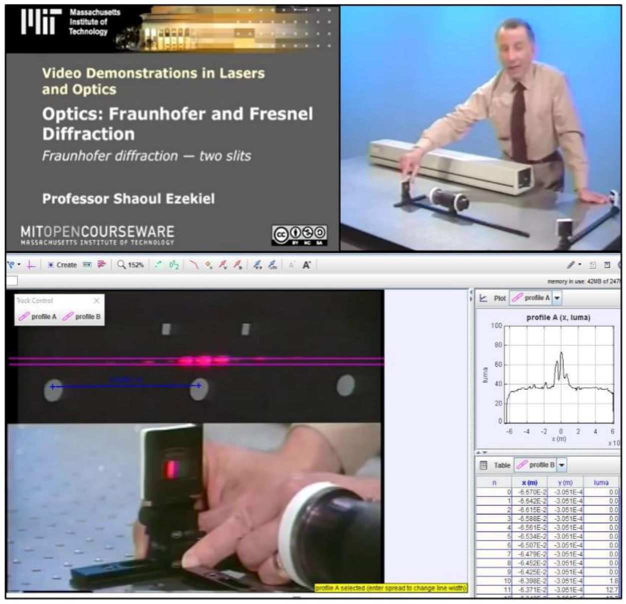

Figure 1. (a) Fraunhofer diffraction experiment presented on MIT Open Courseware video demonstration. (b) Diffraction pattern analysis using Video *Tracker* Software

RESULTS

Experiment with double slit

In the experiment with a double slit, the slit spacing is adjusted then the diffraction spectra are analyzed. The slit spacing is varied to be 150, 200, and 300 μm. The diffraction pattern obtained from analysis with *Tracker* is depicted in Fig. 2. Using the same parameters with the experiment ($L = 2$ m, $d = 100\mu$m, and $\lambda = 6328$ Å), we plot the diffraction pattern at double slit according to Eq (1) (see Fig. 3).

The experimental pattern is not as smooth as the theoretical pattern. It may be due to the limitation in the experiment itself or the limitation of the imaging technique. However, qualitatively the experimental pattern shows a similar pattern with the theoretical pattern for the diffraction at the double slit. As the slit spacing increases, the width of the central and nearby maxima becomes narrower. The location of the first and second maxima also shifts closer to $\theta = 0$, as the slit spacing increases.

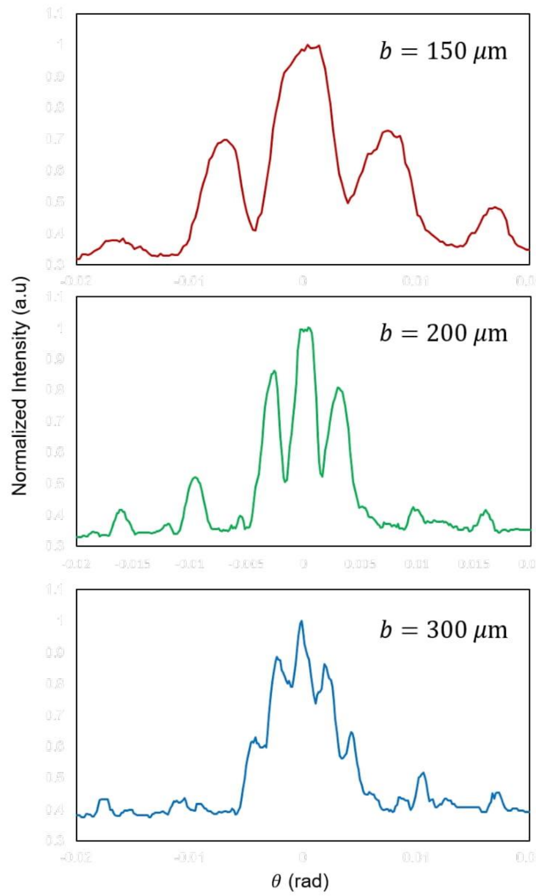

Figure 2. Experimental double-slit diffraction pattern with various slit spacing. In the experiment, the distance between the slit and the screen (L) is fixed, 2 m. The slit width (d) used is 100 μm. The laser used is helium laser with $\lambda = 6328$ Å.

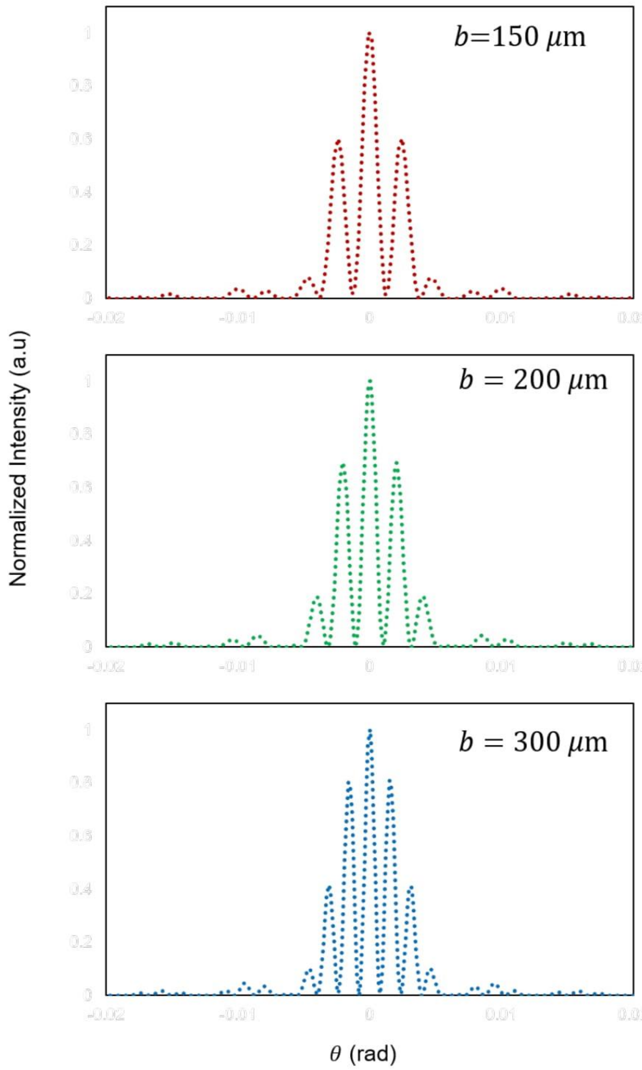

Figure 2. Theoretical double-slit diffraction pattern with various slit spacing. The used parameters are $L = 2$ m, $d = 100\mu$m, and $\lambda = 6328$ Å

Experiment with multiple slit

For multiple slit experiments, the number of slits (N) is varied. The slit width (d) and spacing (b) are fixed to 50 and 75 μm, respectively. Fig. 4 shows the diffraction pattern obtained from video analysis with *Tracker*. Whereas Fig. 5 shows the diffraction pattern got theoretically by plotting Eq. (1) with the same parameters in the experiment ($L = 2$ m, $d = 50\mu$m, $b = 75$ μm, and $\lambda = 6328$ Å).

Similar to the double-slit experiment result, the experimental diffraction patterns at multi slits are also not as smooth as the theoretical prediction. However, the same trend is observed. As the number of slits increases, the width of the maxima becomes narrower. However, the location of the peaks does not change as the number of slit increases. For a more significant number of the slit, small peaks arise between central and first maxima.

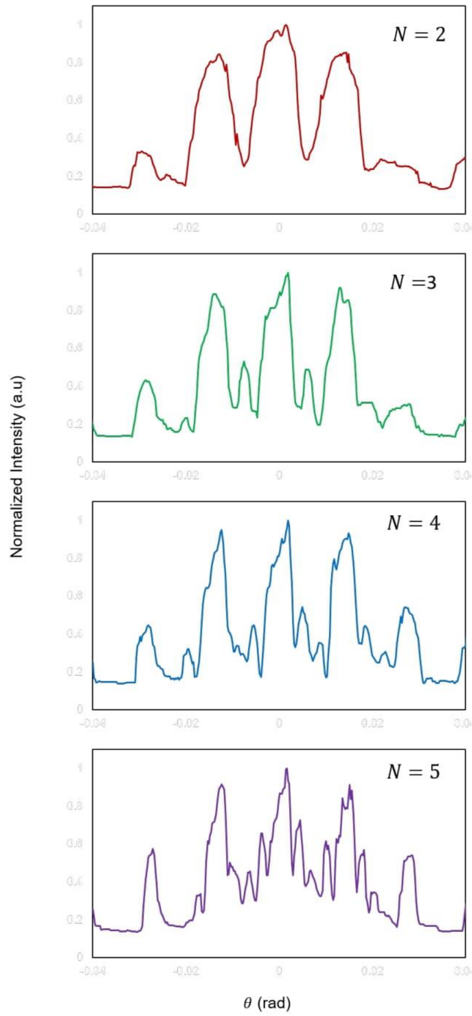

Figure 4. Experimental diffraction pattern with various slit numbers. In the experiment, the distance between the slit and the screen (L) is fixed, 2 m. The slit width (d) and the slit spacing (b) used are 50 and 75 μm, respectively. The laser used is helium laser with $\lambda = 6328$ Å.

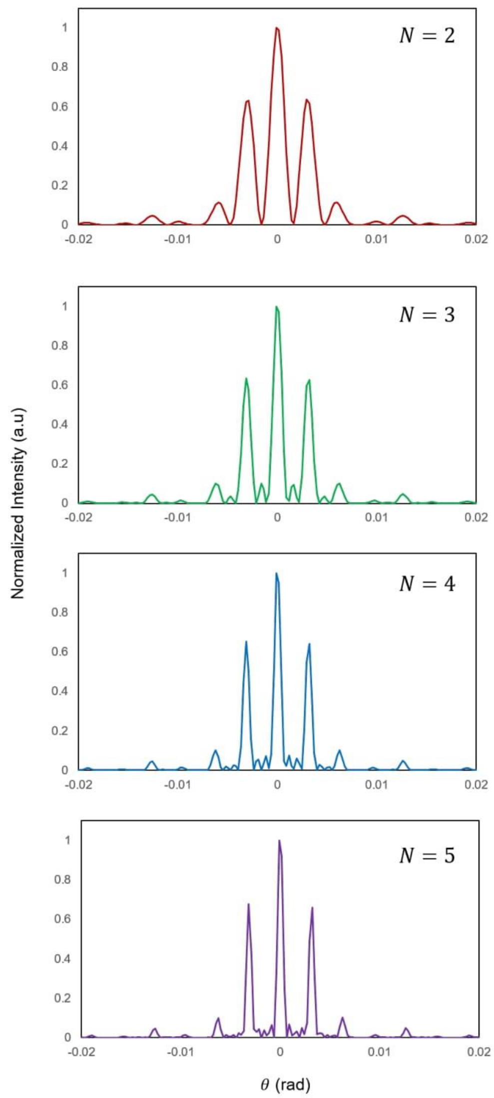

Figure 5. Theoretical diffraction pattern with various slit numbers. The used parameters are $L = 2$ m, $d = 50 \mu$m, $b = 75\ \mu$m, and $\lambda = 6328$ Å

IMPLEMENTATION IN LEARNING PROCESS

In distance learning, laboratory activity is hard to be conducted. Activity with video analysis and spreadsheets can be an alternative option. Through the activity, students can develop their science process skills and conceptual understanding in Fraunhofer diffraction. They also can improve mathematical and computational thinking skills.

In the teaching and learning process, the teacher can begin by presenting the Fraunhofer Diffraction video demonstration from MIT Open CourseWare. Meanwhile, students are asked to observe the Fraunhofer diffraction phenomena in the video. After the observation, the teacher can ask students to analyze the light spectra using the *Tracker*. However, teachers need to give an introduction to *Tracker* beforehand. After students get some findings, they should present their findings in the class forum. The activity can be continued with a discussion of Fraunhofer Diffraction through a mathematical approach. The teacher can encourage students to visualize the obtained mathematical equation with the spreadsheet. The discussion may enrich students with a theoretical explanation about their observation.

The video analysis activity can be carried out as a project or homework. This learning scenario will engage students more in ‘virtual’ physics experiments, and students may become more motivated in learning physics.

CONCLUSION

Learning Fraunhofer diffraction using video *Tracker* and spreadsheet enables students to compare experimental and theoretical results. This activity is the potential to be used in distance learning to accommodate laboratory-related physics course.

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2.	**Bukti konfirmasi review dan hasil review (accepted with minor revision)**	**14 Juni 2020**

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Gmail **Elisabeth Founda <elisa.founda@gmail.com>**

[RMF E] Editor Decision

10 messages

Prof. Alejandro Ayala <rmf@ciencias.unam.mx> Sun, Jun 14, 2020 at 7:55 PM
To: "Ms. Elisabeth FOUNDA Pratidhina" <elisa.founda@gmail.com>

Dear Ms Elisabeth FOUNDA Pratidhina:

Please find enclosed the referee's comments on your work: "Exploring Fraunhofer Diffraction Through Tracker and Spreadsheet: An Alternative Lab Activity for Distance Learning" submitted to Revista Mexicana de Física E.

According to the referee's report, your work requires some changes and improvements addressing these comments before it can be considered again for publication.

When resubmitting please include a detailed list of all changes made along with the new version of the paper in pdf format.

Prof. Alejandro Ayala
Chief Editor
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Suggestions to the authors:

In **INTRODUCTION**

Recently, distance learning and blended learning are ~~being~~ popular. (Remove "being")

One ~~of the~~ efficient ways is ~~by utilizing~~ to use existing ~~the existed~~ resources and technologies.

For physics teachers, the challenge is migrating lab activities ~~from the traditional model~~ to the digital model.

Instead of taking data by hands-on measurement, students can take data by ~~observing the video. Furthermore, to get more in-depth analysis, the video can be analyzed using video-analysis software, such as in *Tracker*~~ video analysis using a software such as Tracker.

(Comment from the reviwer: When students take data from a video, they are already analyzing the video, not only observing it.)

In this work, we present the use of these two didactic tools, i.e., Tracker and spreadsheet, ~~in physics, distance learning activity~~ for a distance learning activity in physics.

In **THEORY OF DIFFRACTION**

It occurs when a portion of the wavefront is obstructed in some way or encounters one (or many) slits, and the wavefront is altered in amplitude or phase.

In **METHOD**

It would be nice if some extra detail were added to guide the reader inside the tracker to achieve the desired result, such as: "create new, line profile, etc."

In **RESULTS**

“Figure 2” appears two times. The latter is “Figure 3”.

In **CONCLUSIONS**

This activity ~~is~~ has the potential…

In **REFERENCES**

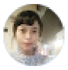
[12] M. Rodrigues and ~~S. C. P~~ P. S. Carvalho. “Teaching optical phenomena with Tracker,” Phys. Educ., vol. 49, no. 6, pp. 671–677, 2014.

GENERAL REMARKS

Regarding the Reviewer Guidelines every item seems adequate, provided the authors do a revision.

In addition, would be very interesting if the authors consider to include a section regarding “Fraunhofer Diffraction — Multiple Slits - https://ocw.mit.edu/resources/res-6-006-video-demonstrations-in-lasers-and-optics-spring-2008/demonstrations-in-physical-optics/fraunhofer-diffraction-2014-multiple-slits/ ” also from their own reference [1].

I suggest this because it is very simple and easy to calculate the light wavelength with a diffraction grating experiment. Then the students could compare their findings with the given value in the video (λ=6328 Å).



Elisabeth Founda <elisa.founda@gmail.com> Jun 14, 2020, 8:02 PM

to Alejandro

Thank you for your email.

We will revise the manuscript and re-submit it as soon as possible.

•••

3.	**Bukti submit revisi pertama**	**16 Juni 2020**

Elisabeth Founda <elisa.founda@gmail.com> Tue, Jun 16, 2020 at 12:20 PM
To: "Prof. Alejandro Ayala" <rmf@ciencias.unam.mx>

Dear Prof. Alenjandro Ayala
Chief Editor of Revista Mexicana de Fisica E

We would like to resubmit our article entitled "Exploring Fraunhofer Diffraction Through Tracker and Spreadsheet: An Alternative Lab Activity for Distance Learning" to Revista Mexicana de Física E.

We have revised our manuscript based on the reviewer's comments. Beside the revised manuscript, we attach the reply letter in this email.
The reply letter provides our detailed responses to the reviewer's comments.

We really hope that our manuscript can be published in Revista Mexicana de Física E.

Thank you.
[Quoted text hidden]
[Quoted text hidden]

2 attachments

Elisabeth et al_reply letter_Exploring Fraunhofer Diffraction Through Tracker and Spreadsheet.pdf
551K

Elisabeth et al_revised manuscript_Exploring Fraunhofer Diffraction Through Tracker and Spreadsheet.docx
3657K

Reply to Reviewer

In **INTRODUCTION**

Reviewer's Comment)

Recently, distance learning and blended learning are ~~being~~ popular. (Remove "being")
One ~~of the~~ efficient ways is ~~by utilizing~~ to use existing ~~the existed~~ resources and technologies.

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(Comment from the reviwer: When students take data from a video, they are already analyzing the video, not only observing it.)

In this work, we present the use of these two didactic tools, i.e., Tracker and spreadsheet~~, in physics, distance learning activity~~ for a distance learning activity in physics

Author reply)

We have revised the introduction based on the suggestion from reviewer

In **THEORY OF DIFFRACTION**

Reviewer's Comment)

It occurs when a portion of the wavefront is obstructed in some way or encounters one (or many) slits, and the wavefront is altered in amplitude or phase.

Author reply)

We have revised the sentence in accordance to the suggestion from reviewer. Moreover, we added a short discussion regarding the equation which can be used to calculate the wavelength of the light. The following is the added sentences:

In Fraunhofer diffraction with multiple slits, there are regularly spaced principal maxima and some smaller maxima which lay in between the principal maxima. The principal maxima spacing on the screen follows relation:

$$\sin\theta_n = \frac{n\lambda}{S_n}, \quad n = 0, \pm 1, \pm 2, \ldots \tag{2}$$

By using approximation $\sin\theta_n \approx \frac{\Delta}{L}$, *Eq. (2) can be written as:*

$$S_n = \frac{Ln\lambda}{\Delta}, \tag{3}$$

where S_n *is the fringe spacing on the screen,* L *is the distance between the slit and the screen,* λ *is the wavelength,* Δ *is the slit separation, and* n *is an index of the maxima. For diffraction gratting, slit separation can be calculated from* $\Delta = \frac{1}{grating\ constant}$.

In **METHOD**

Reviewer's Comment)

It would be nice if some extra detail were added to guide the reader inside the tracker to achieve the desired result, such as: "create new, line profile, etc."

Author reply)

Thank you very much for the suggestions upon the Method of the manuscript. In order to accommodate the reviewer's suggestion, we added these following sentences:

When we start video analysis in Tracker, we have to import the video by selecting File > Import > Video; then we choose the video that we want to analyze. For calibration, we need to select Track Menu > New > Calibration Tool > Calibration Stick. We can mark two calibration points by using shift keyboard and click. After two points are marked, we have to input the actual distance of those two points. By doing this, the length of objects in the video has been calibrated to their actual length. For intensity analysis, we need to choose Track Menu > New > Line Profile. We can select the region which we want to analyze by pressing shift keyboard and mouse click. The line region can be expanded by mouse click and drag. The intensity and position data will be presented as graph and table in the right side of Tracker program.

After we get the data about point position and intensity in Tracker, we bring them to a spreadsheet program to plot the spectra. Then, we plot Eq. (1) with the given parameters in the experiment to provide a theoretical comparison.

In this work, we conducted 3 investigations, i.e.

a. Double Slits Experiment with Slit Spacing Variation, in which we use a video entitled "Fraunhofer Diffraction-Two Slits" in MIT Open Couse Ware [18].

b. Multiple Slits Experiment with Number of Slit Variation, in which we use the first part of a video entitled "Fraunhofer Diffraction-Multiple Slits" in MIT Open Couse Ware [19].

c. Diffraction Grating Experiment with Variation of Grating Constant, in which we use the second part of a video entitled "Fraunhofer Diffraction-Multiple Slits" in MIT Open Couse Ware [19].

In **RESULTS**

Reviewer's Comment)

"Figure 2" appears two times. The latter is "Figure 3"

Author reply)

We have fixed this mistake in the manuscript.

In **CONCLUSIONS**

Reviewer's Comment)

This activity ~~is~~ has the potential…

Author reply)

We have fixed this mistake in the manuscript

In **REFERENCES**

Reviewer's Comment)

[12] M. Rodrigues and ~~S. C. P~~ P. S. Carvalho. "Teaching optical phenomena with Tracker," Phys. Educ., vol. 49, no. 6, pp. 671–677, 2014.

Author reply)

We have fixed the references.

GENERAL REMARKS

Reviewer's Comment)

Regarding the Reviewer Guidelines every item seems adequate, provided the authors do a revision.

In addition, would be very interesting if the authors consider to include a section regarding "Fraunhofer Diffraction — Multiple Slits - https://ocw.mit.edu/resources/res-6-006-video-demonstrations-in-lasers-and-optics-spring-2008/demonstrations-inphysical-optics/fraunhofer-diffraction-2014-multiple-slits/ " also from their own reference [1].

I suggest this because it is very simple and easy to calculate the light wavelength with a diffraction grating experiment. Then the students could compare their findings with the given value in the video

Author reply)

Thank you very much for the comments by the Reviewer**.** To accommodate reviewer's suggestion regarding to the calculation of wavelength, we added additional discussion in the RESULT:

Diffraction Grating Experiment with Variation of Grating Constant

The experiment is continued with diffraction gratting. In this experiment, the gratting constant is varied. The used gratting constants are 100, 200, and 300 lines/inch. The intensity of the Fraunhofer diffraction pattern is presented in Fig. 6. It can be seen that as the gratting constant increases, the distance between principal maxima or fringe spacing become wider. By using the intensity profile in Fig. 6 and Eq. (3) , we also can determine the wavelength of the laser. The calculated wavelength from the experiment is $6.160 \pm 0.037 \times 10^{-7}$ *m (see Table 1). This value is slightly below the reference value (6.328×* 10^{-7} *m) that given in the video explanation.*

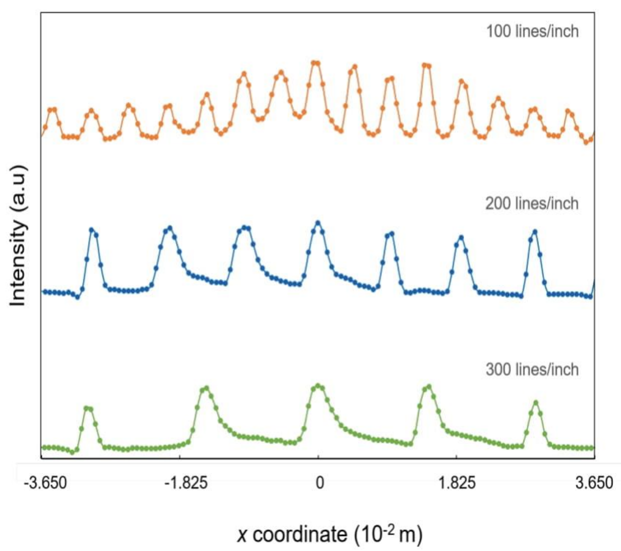

Figure 6. Intensity profile of Fraunhofer Diffraction By Grating with various grating constant

Tabel 1. Wavelength Calculation

L (m)	Δ (x 10^{-4} m)	n	S_n (m)	λ (x 10^{-7} m)
2	2.540	1	0.0048	6.096
2	1.270	1	0.0098	6.223
2	0.847	1	0.0146	6.181
$\bar{\lambda} = 6.160 \pm 0.037 \times 10^{-7}\ m$				

1. D. Brown, "*Tracker: Video Analysis and Modeling Tool*", Physlets.org, https://physlets.org/tracker/.
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Exploring Fraunhofer Diffraction Through *Tracker* and Spreadsheet: An Alternative Lab Activity for Distance Learning

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ABSTRACT

In this paper, we present an alternative for physics laboratory activity related to Fraunhofer diffraction in distance learning. The activity utilizes a demonstration video from MIT Open CourseWare, Tracker software, and spreadsheet. An online demonstration video is used because it is the most accessible resource during undesirable conditions such as COVID 19 pandemic. In the activity, students can explore diffractions phenomena with multiple slits. The effect of slit spacing and slit numbers to the intensity of light is investigated trough spectral analysis with Tracker. The investigation is followed by a discussion through the mathematical approach and visualization with spreadsheets. It will enrich students with a theoretical explanation of the observation. This distance learning activity allows students to develop their science process skills, mathematical and computational thinking skills, and conceptual understanding of Fraunhofer diffraction.

Keyword: Fraunhofer diffraction, Tracker, Spreadsheet, Distance Learning

INTRODUCTION

Recently, distance learning and blended learning are popular. Notably, during the undesirable pandemic, the governments, school principals, and teachers are forced to change traditional classrooms into the digital classes. In a short time, teachers have to think about how to teach their students effectively in distance learning mode. One efficient ways is the existed resources and technologies.

For physics teachers, the challenge is migrating lab activities to the digital model. Several experiment resources are available online; one of them is *Demonstrations in physical optics* provided by MIT Open Course Ware [1]. The resources include various demonstrations about optical phenomena such as polarization, diffraction, and propagation in optical fiber. That kind of resource can be used to teach physics in distance learning mode. Instead of taking data by hands-on measurement, students can take data by video analysis using a software such as *Tracker*.

Tracker is useful free software in physics education, which is developed on the Open Source Physics Java code library. People use it for video analysis and physics modeling. By using *Tracker*, users can track an object's position, velocity, and accelerations [2]. It also has a calibration feature to calibrate the length quantity in the video to the real one. Moreover, the RGB line profile feature in *Tracker* can be used to analyze spectra.

Tracker has been used for pedagogical purposes and complex physics experiments. Educators and scientist use *Tracker* to teach and study various topics such as vector, object falling in liquid and air [3], projectile motion [4], [5], mechanical energy [6], kater pendulum [7], damped harmonic oscillation [8], torsion [9], impulse [10], astronomy [11], and optical geometry [12]. *Tracker* is a potential tool to promote and guide the student as a scientist. Students can explore the laws of nature with *Tracker*. By using video modeling, students can practice to ask questions, use models, and develop mathematical and computational thinking [13]. It also encourages students to think creatively and improve their physics learning performance [14].

Spreadsheets such as *Ms. Excel* are powerful computing and graphical tools. In physics education, we can build simple simulations and visualization in the spreadsheet when we are discussing a physics equation [15], [16].

In this work, we present the use of these two didactic tools, i.e., *Tracker* and spreadsheet, for a distance learning activity in physics. We utilize *Tracker* to analyze the Fraunhofer diffraction pattern at double and multiple slits. Instead of record a video from a direct experiment, we use the available demonstration video resources from MIT Open Course Ware. Then, the observed pattern from *Tracker* analysis is compared to the theory by utilizing the spreadsheet program, *Ms. Excel.*

THEORY OF DIFFRACTION

One of the phenomena which can prove the wave nature of light is diffraction. It occurs when a portion of the wavefront is obstructed in some way or encounters one (or many) slits, and the wavefront is altered in amplitude or phase. Segments of wavefront which propagate beyond the obstacle interfere and construct diffraction pattern [17]. There are two kinds of diffractions, i.e., Fresnel diffraction and Fraunhofer diffractions. In Fraunhofer diffraction, the incoming and outgoing waves approach must be planar over the extent of the obstacles. Fraunhofer diffraction occurs when the distance between the obstacle and the screen is far enough.

The obstacles for Fraunhofer diffraction can be a single slit, double slits, and multiple slits. The multiple slits can be a diffraction grating. For Fraunhofer diffraction at N parallel slits, the intensity distribution is given by Eq. (1).

$$I(\theta) = I_0 \left(\frac{\sin \beta}{\beta}\right)^2 \left(\frac{\sin N\alpha}{\sin \alpha}\right)^2 \tag{1}$$

With,

$$\alpha \equiv \frac{\pi(b+d)\sin\theta}{\lambda},$$

$$\beta \equiv \frac{\pi d}{\lambda}\sin\theta,$$

where d is the slit width, b is the slit spacing, λ is the wavelength of the light, θ is the observation angle, and I_0 is the intensity of the center maxima, i.e., the intensity in the $\theta = 0$ rad.

In Fraunhofer diffraction with multiple slits, there are regularly spaced principal maxima and some smaller maxima which lay in between the principal maxima. The principal maxima spacing on the screen follows relation:

$$\sin\theta_n = \frac{n\lambda}{S_n}, \quad n = 0, \pm 1, \pm 2, \ldots \tag{2}$$

By using approximation $\sin\theta_n \approx \frac{\Delta}{L}$, Eq. (2) can be written as:

$$S_n = \frac{Ln\lambda}{\Delta}, \tag{3}$$

where S_n is the fringe spacing on the screen, L is the distance between the slit and the screen, λ is the wavelength, Δ is the slit separation, and n is an index of the maxima. For diffraction grating, slit separation can be calculated from $\Delta = \frac{1}{\text{grating constant}}$.

METHOD

We use the Fraunhofer diffraction demonstration video available in MIT Open Couse Ware [1]. The diffraction pattern in the video is analyzed by using *Tracker* software. *Tracker* software allows tracking line profiles, which give the data about intensity (luma) at specific points. *Tracker* also allows calibration to match the dimension, such as length, in the video to the real dimension. Fig. 1 shows how the setup of *Tracker* looks like.

When we start video analysis in *Tracker*, we have to import the video by selecting File > Import > Video; then we choose the video that we want to analyze. For calibration, we need to select Track Menu > New > Calibration Tool > Calibration Stick. We can mark two calibration points by using shift keyboard and click. After two points are marked, we have to input the actual distance of those two points. By doing this, the length of objects in the video has been calibrated to their actual length. For intensity analysis, we need to choose Track Menu > New > Line Profile. We can select the region which we want to analyze by pressing shift keyboard and mouse click. The line region can be expanded by mouse click and drag. The intensity and position data will be presented as graph and table in the right side of *Tracker* program.

After we get the data about point position and intensity in *Tracker*, we bring them to a spreadsheet program to plot the spectra. Then, we plot Eq. (1) with the given parameters in the experiment to provide a theoretical comparison.

In this work, we conducted 3 investigations, i.e.

a. Double Slits Experiment with Slit Spacing Variation, in which we use a video entitled "Fraunhofer Diffraction-Two Slits" in MIT Open Couse Ware [18].
b. Multiple Slits Experiment with Number of Slit Variation, in which we use the first part of a video entitled "Fraunhofer Diffraction-Multiple Slits" in MIT Open Couse Ware [19].
c. Diffraction Grating Experiment with Variation of Grating Constant, in which we use the second part of a video entitled "Fraunhofer Diffraction-Multiple Slits" in MIT Open Couse Ware [19].

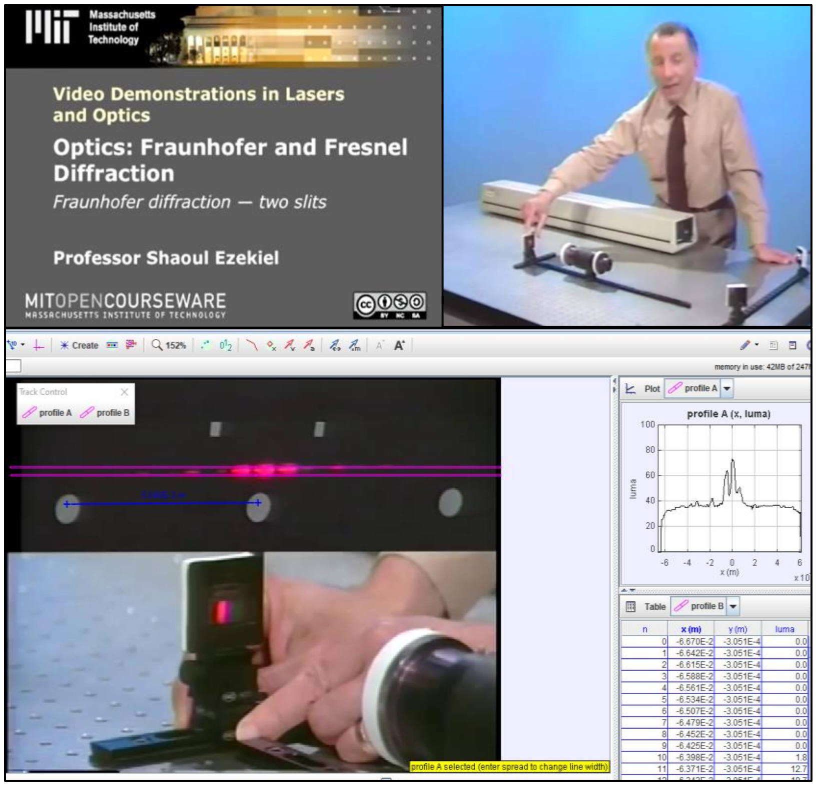

Figure 1. (a) Fraunhofer diffraction experiment presented on MIT Open Courseware video demonstration. (b) Diffraction pattern analysis using Video *Tracker* Software

RESULTS

Double Slits Experiment with Slit Spacing Variation

In the experiment with double slits, the slit spacing is adjusted then the diffraction spectra are analyzed. The slit spacing is varied to be 150, 200, and 300 μm. The diffraction pattern obtained from analysis with *Tracker* is depicted in Fig. 2. Using the same parameters with the experiment ($L = 2$ m, $d = 100\mu$m, and $\lambda = 6328$ Å), we plot the diffraction pattern at double slit according to Eq (1) (see Fig. 3).

The experimental pattern is not as smooth as the theoretical pattern. It may be due to the limitation in the experiment itself or the limitation of the imaging technique. However, qualitatively the experimental pattern shows a similar pattern with the theoretical intensity profile for the diffraction at the double slits. As the slit spacing increases, the width of the central and nearby maxima becomes narrower. The location of the first and second maxima also shifts closer to $\theta = 0$, as the slit spacing increases.

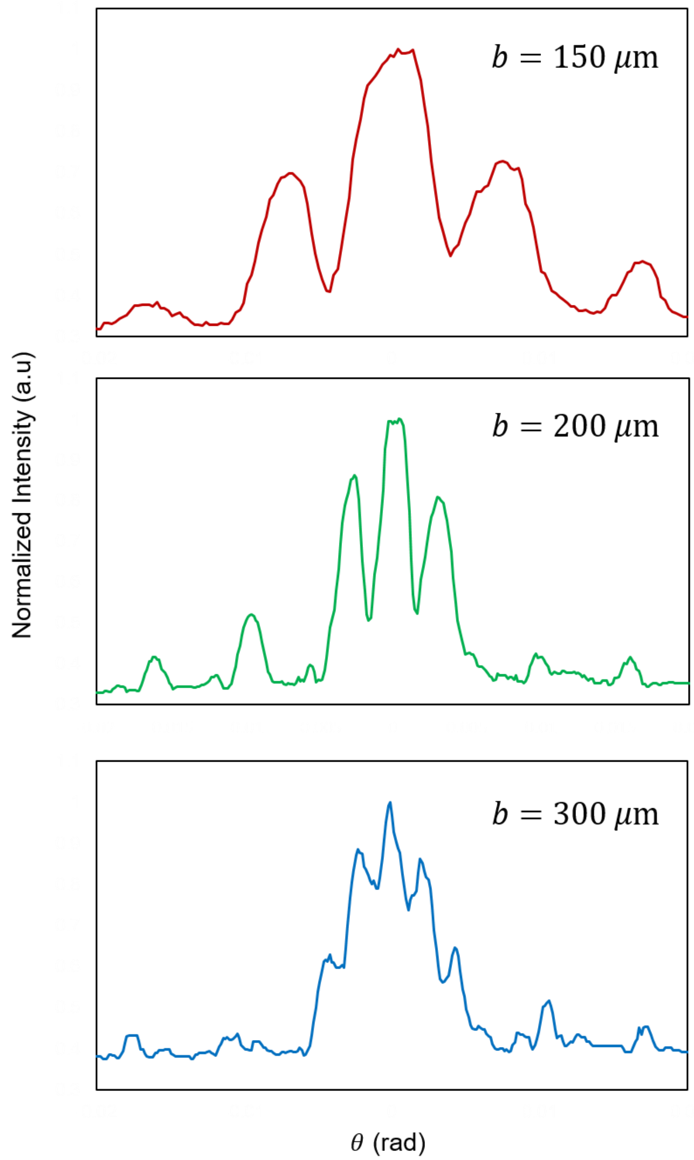

Figure 2. Experimental double slits diffraction pattern with various slit spacing. In the experiment, the distance between the slit and the screen (L) is fixed, 2 m. The slit width (d) used is 100 μm. The laser used is helium laser with $\lambda = 6328$ Å.

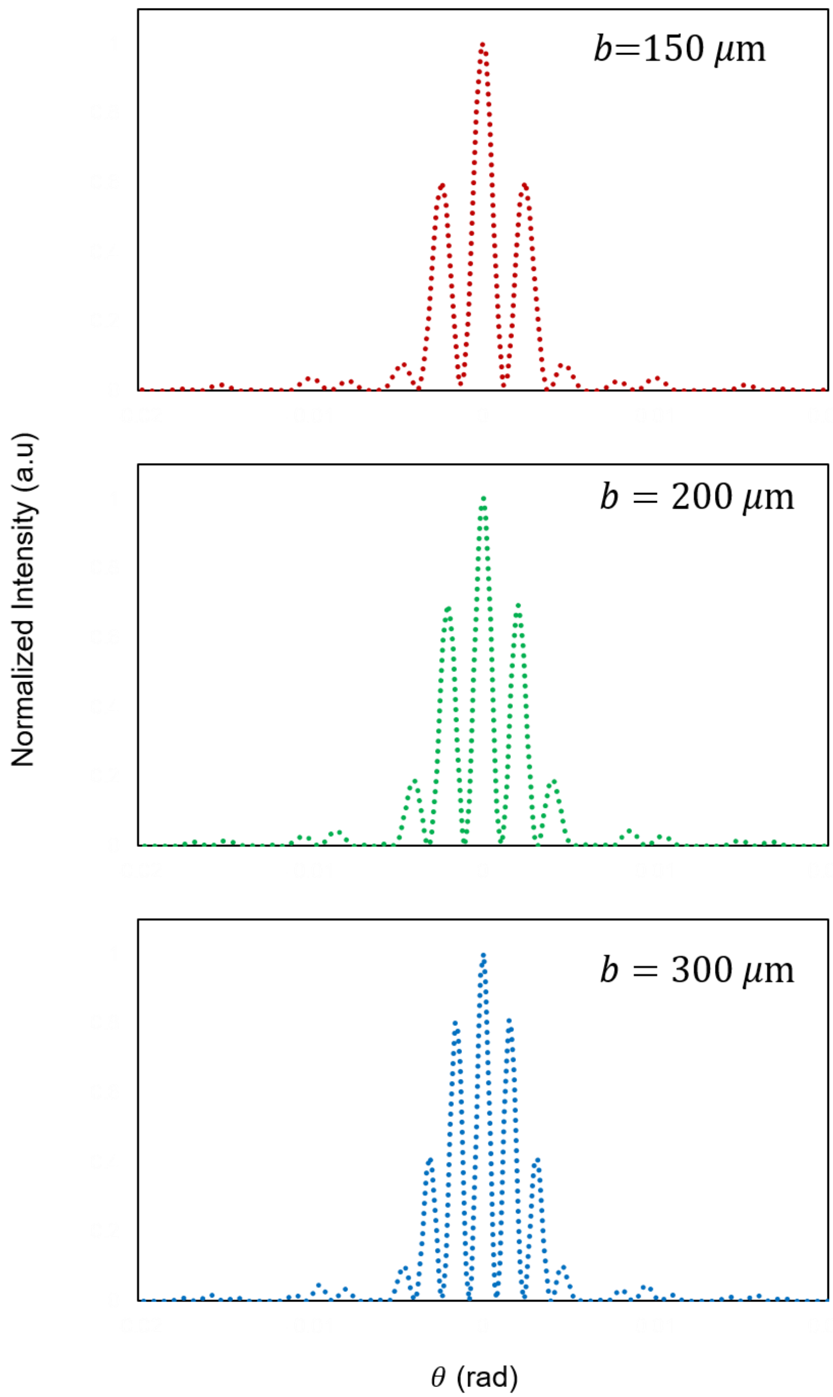

Figure 3. Theoretical double-slit diffraction pattern with various slit spacing. The used parameters are $L = 2$ m, $d = 100\mu$m, and $\lambda = 6328$ Å

Multiple Slits Experiment with Number of Slits Variation

For multiple slits experiments, the number of slits (N) is varied. The slit width (d) and spacing (b) are fixed to 50 and 75 μm, respectively. Fig. 4 shows the diffraction pattern obtained from video analysis with *Tracker*. Whereas Fig. 5 shows the diffraction pattern got theoretically by plotting Eq. (1) with the same parameters used in the experiment ($L = 2$ m, $d = 50 \mu$m, $b = 75$ μm, and $\lambda = 6328$ Å).

Similar to the double-slit experiment result, the experimental diffraction patterns at multiple slits are also not as smooth as the theoretical prediction. However, the same trend is observed. As the number of slits increases, the width of the maxima becomes narrower. For $N > 2$, small peaks/small maxima arise between principal maxima.

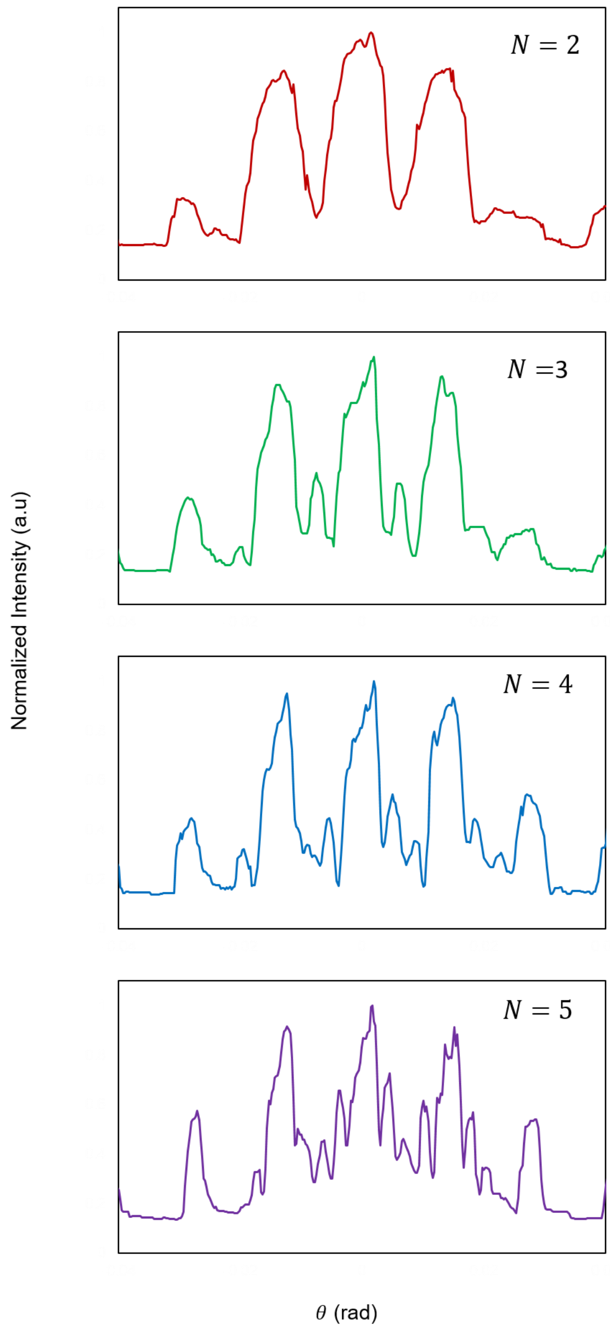

Figure 4. Experimental diffraction pattern with various slits number. In the experiment, the distance between the slit and the screen (L) is fixed, 2 m. The slit width (d) and the slit spacing (b) used are 50 and 75 μm, respectively. The laser used is helium laser with $\lambda = 6328$ Å.

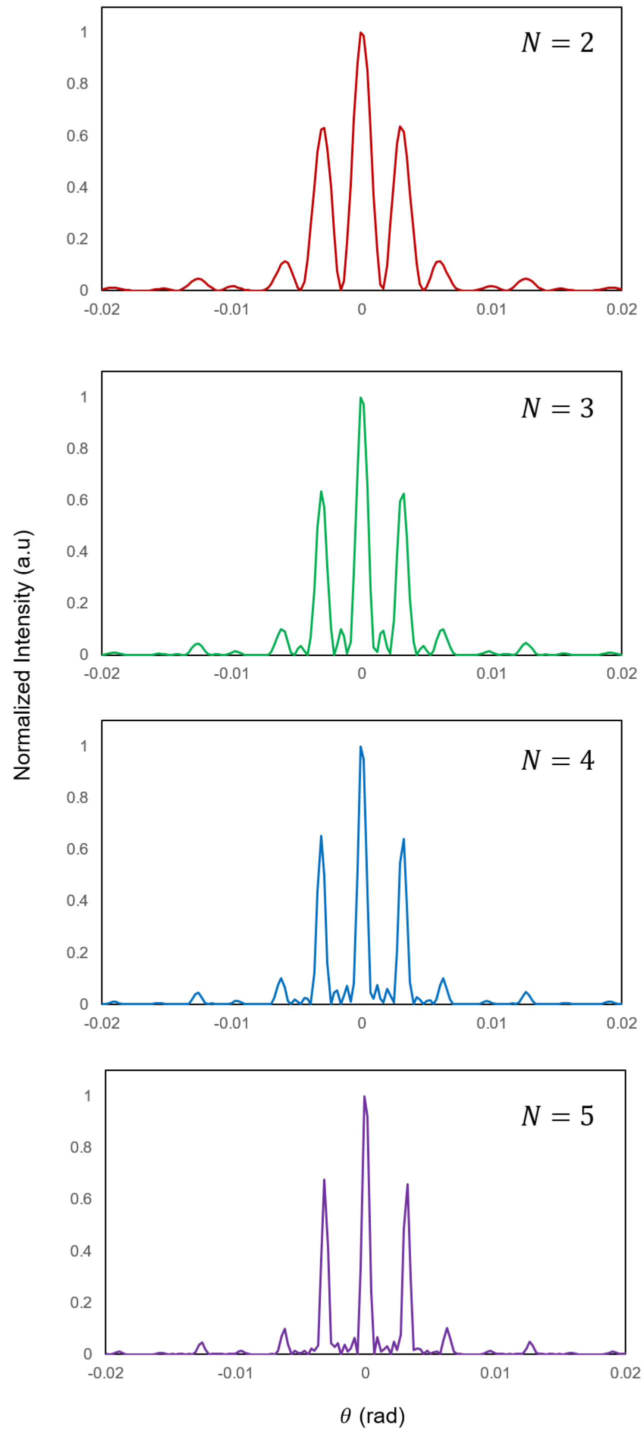

Figure 5. Theoretical diffraction pattern with various slits number. The used parameters are $L = 2$ m, $d = 50 \mu$m, $b = 75\ \mu$m, and $\lambda = 6328$ Å

Diffraction Grating Experiment with Variation of Grating Constant

The experiment is continued with diffraction grating. In this experiment, the grating constant is varied. The used grating constants are 100, 200, and 300 lines/inch. The intensity of the Fraunhofer diffraction pattern is presented in Fig. 6. It can be seen that as the grating constant increases, the distance between principal maxima or fringe spacing become wider. By using the intensity profile in Fig. 6 and Eq. (3) , we also can determine the wavelength of the laser. The calculated wavelength from the experiment is $6.160 \pm 0.037 \times 10^{-7}$ m (see Table 1). This value is slightly below the reference value (6.328×10^{-7} m) that given in the video explanation.

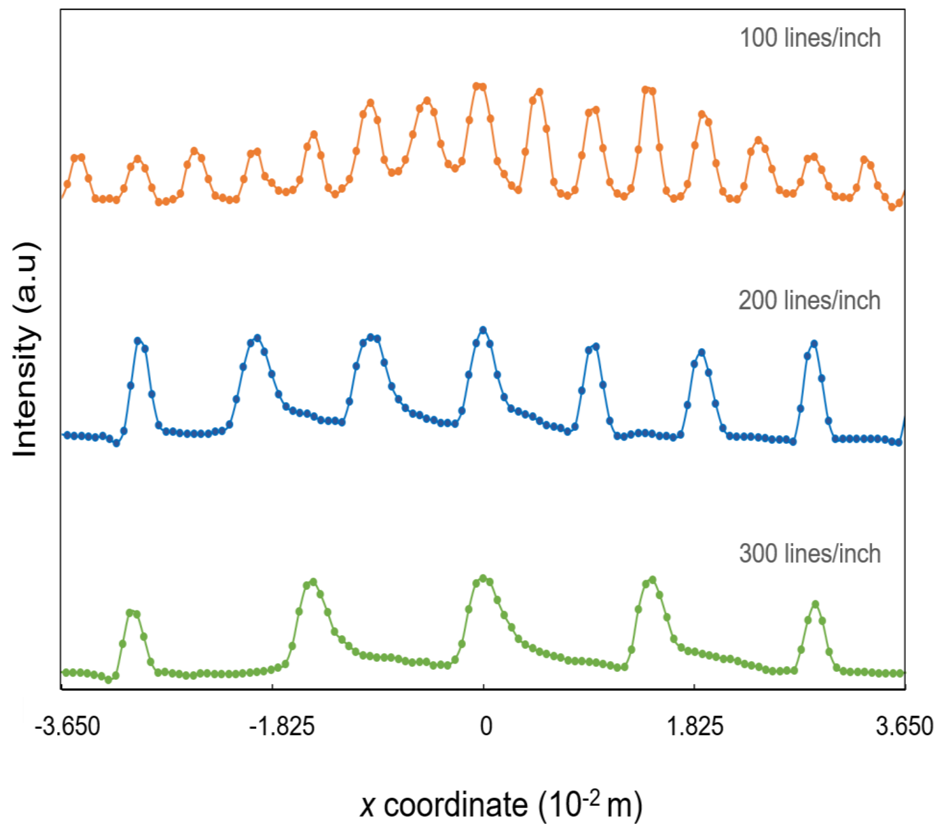

Figure 6. Intensity profile of Fraunhofer Diffraction By Grating with various grating constant

Tabel 1. Wavelength Calculation

L (m)	Δ (x 10^{-4} m)	n	S_n (m)	λ (x 10^{-7} m)
2	2.540	1	0.0048	6.096
2	1.270	1	0.0098	6.223
2	0.847	1	0.0146	6.181
$\bar{\lambda} = 6.160 \pm 0.037 \times 10^{-7}$ m				

IMPLEMENTATION IN LEARNING PROCESS

In distance learning, laboratory activity is hard to be conducted. Activity with video analysis and spreadsheets can be an alternative option. Through the activity, students can develop their science process skills and conceptual understanding in Fraunhofer diffraction. They also can improve mathematical and computational thinking skills.

In the teaching and learning process, the teacher can begin by presenting the Fraunhofer Diffraction video demonstration from MIT Open CourseWare. Meanwhile, students are asked to observe the Fraunhofer diffraction phenomena in the video. After the observation, the teacher can ask students to analyze the light spectra using the *Tracker*. However, teachers need to give an introduction to *Tracker* beforehand. After students get some findings, they should present their findings in the class forum. The activity can be continued with a discussion of Fraunhofer Diffraction through a mathematical approach. The teacher can encourage students to visualize the obtained mathematical equation with the spreadsheet. The discussion may enrich students with a theoretical explanation about their observation.

The video analysis activity can be carried out as a project or homework. This learning scenario will engage students more in 'virtual' physics experiments, and students may become more motivated in learning physics.

CONCLUSION

In this paper, we have presented the investigation of Fraunhofer diffraction with double and multiple slits through *Tracker* and *spreadheet* program. Learning Fraunhofer diffraction using video *Tracker* and spreadsheet enables students to compare experimental and theoretical results.

This activity has the potential to be used in distance learning to accommodate laboratory-related physics course.

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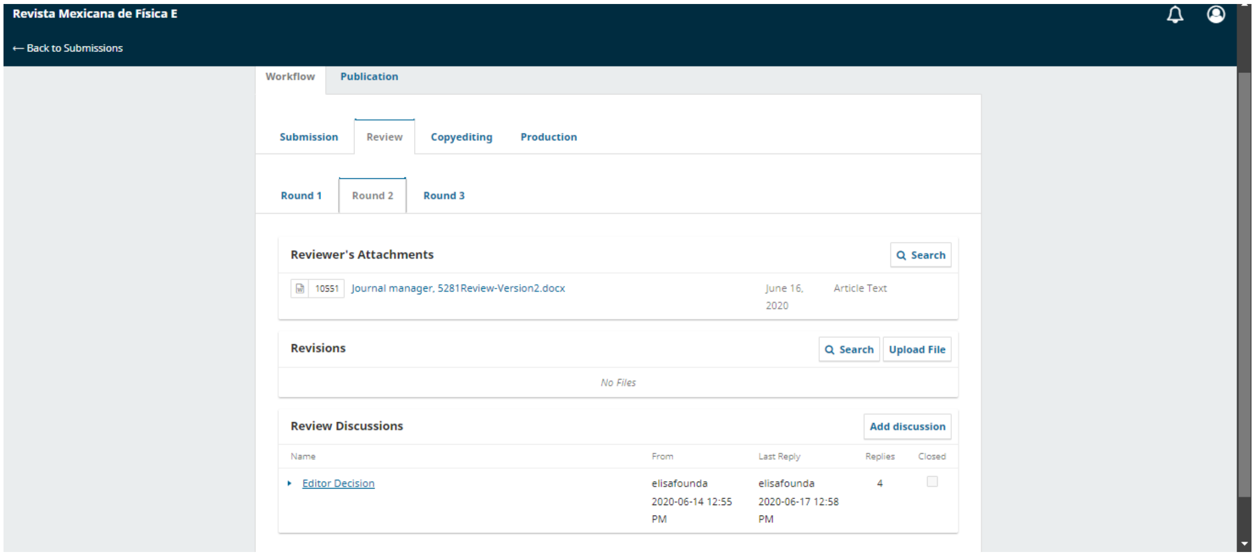
4.	**Bukti review kedua**	**16 Juni 2020**



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Editor Decision	elisafounda 2020-06-14 12:55 PM	elisafounda 2020-06-17 12:58 PM	4	

Dear Ms. Elisabeth FOUNDA Pratidhina:

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2020-06-16 10:28 PM

Please find enclosed the referee's comments on your work: "Exploring Fraunhofer Diffraction Through Tracker and Spreadsheet: An Alternative Lab Activity for Distance Learning" submitted to Revista Mexicana de Física E.

According to the referee's report, your work still requires some minor changes and improvements addressing these comments before it can be considered again for publication.

When resubmitting please include a detailed list of all changes made along with the new version of the paper in pdf format.

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[RMF E] Editor Decision

4 messages

Prof. Alejandro Ayala <rmf@ciencias.unam.mx> Wed, Jun 17, 2020 at 5:28 AM
To: Ms Elisabeth FOUNDA Pratidhina <elisa.founda@gmail.com>

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Suggestions to the authors:

In **INTRODUCTION**

One efficient way~~s is the existed~~ is to use existing resources and technologies.

In **DIFFRACTION GRATING EXPERIMENT WITH VARIATION OF GRATING CONSTANT**

This value is slightly below the reference value (6.328×10^{-7} m) that is given in the video explanation.

GENERAL REMARKS

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5. Bukti revisi kedua 17 Juni 2020

Elisabeth Founda <elisa.founda@gmail.com> Wed, Jun 17, 2020 at 5:42 PM
To: "Prof. Alejandro Ayala" <rmf@ciencias.unam.mx>

Dear Prof. Alenjandro Ayala
Chief Editor of Revista Mexicana de Fisica E

We would like to resubmit our article entitled " Exploring Fraunhofer Diffraction Thorugh Tracker and Spreadsheet: An Alternative Lab Activity for Distance Learning" to Revista Mexicana de Física E.

We have revised our manuscript based on the reviewer's comments. We also attach the reply letter in this email. The reply letter provides our detailed responses to the reviewer's comments.

We really hope that our manuscript can be published in Revista Mexicana de Física E.

Thank you.
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2 attachments

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Reply to Reviewer

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Reviewer comments)

One efficient way~~s is the existed~~ is to use existing resources and technologies.

Author reply)

Thank you for the correction. We have fixed this grammatical error in the manuscript

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Author reply)

We address this issue in the manuscript by adding this following sentence:

"The percentage of discrepancy between the result of the laser wavelength found with Tracker and the reference value given in the video is about 2.6%; which is quite small."

The calculation of the error/discrepancy is given in Table 1.

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THEORY OF DIFFRACTION

One of the phenomena which can prove the wave nature of light is diffraction. It occurs when a portion of the wavefront is obstructed in some way or encounters one (or many) slits, and the wavefront is altered in amplitude or phase. Segments of wavefront which propagate beyond the obstacle interfere and construct diffraction pattern [17]. There are two kinds of diffractions, i.e., Fresnel diffraction and Fraunhofer diffractions. In Fraunhofer diffraction, the incoming and outgoing waves approach must be planar over the extent of the obstacles. Fraunhofer diffraction occurs when the distance between the obstacle and the screen is far enough.

The obstacles for Fraunhofer diffraction can be a single slit, double slits, and multiple slits. The multiple slits can be a diffraction grating. For Fraunhofer diffraction at N parallel slits, the intensity distribution is given by Eq. (1).

$$I(\theta) = I_0 \left(\frac{\sin\beta}{\beta}\right)^2 \left(\frac{\sin N\alpha}{\sin\alpha}\right)^2 \quad (1)$$

With,

$$\alpha \equiv \frac{\pi(b+d)\sin\theta}{\lambda},$$

$$\beta \equiv \frac{\pi d}{\lambda}\sin\theta,$$

where d is the slit width, b is the slit spacing, λ is the wavelength of the light, θ is the observation angle, and I_0 is the intensity of the center maxima, i.e., the intensity in the $\theta = 0$ rad.

In Fraunhofer diffraction with multiple slits, there are regularly spaced principal maxima and some smaller maxima which lay in between the principal maxima. The principal maxima spacing on the screen follows relation:

$$\sin\theta_n = \frac{n\lambda}{S_n}, \quad n = 0, \pm 1, \pm 2, \ldots \quad (2)$$

By using approximation $\sin\theta_n \approx \frac{\Delta}{L}$, Eq. (2) can be written as:

$$S_n = \frac{Ln\lambda}{\Delta}, \quad (3)$$

where S_n is the fringe spacing on the screen, L is the distance between the slit and the screen, λ is the wavelength, Δ is the slit separation, and n is an index of the maxima. For diffraction grating, slit separation can be calculated from $\Delta = \frac{1}{\text{grating constant}}$.

METHOD

We use the Fraunhofer diffraction demonstration video available in MIT Open Couse Ware [1]. The diffraction pattern in the video is analyzed by using *Tracker* software. *Tracker* software allows tracking line profiles, which give the data about intensity (luma) at specific points.

Tracker also allows calibration to match the dimension, such as length, in the video to the real dimension. Fig. 1 shows how the setup of *Tracker* looks like.

When we start video analysis in *Tracker*, we have to import the video by selecting File > Import > Video; then we choose the video that we want to analyze. For calibration, we need to select Track Menu > New > Calibration Tool > Calibration Stick. We can mark two calibration points by using shift keyboard and click. After two points are marked, we have to input the actual distance of those two points. By doing this, the length of objects in the video has been calibrated to their actual length. For intensity analysis, we need to choose Track Menu > New > Line Profile. We can select the region which we want to analyze by pressing shift keyboard and mouse click. The line region can be expanded by mouse click and drag. The intensity and position data will be presented as graph and table in the right side of *Tracker* program.

After we get the data about point position and intensity in *Tracker*, we bring them to a spreadsheet program to plot the spectra. Then, we plot Eq. (1) with the given parameters in the experiment to provide a theoretical comparison.

In this work, we conducted 3 investigations, i.e.

a. Double Slits Experiment with Slit Spacing Variation, in which we use a video entitled “Fraunhofer Diffraction-Two Slits” in MIT Open Couse Ware [18].
b. Multiple Slits Experiment with Number of Slit Variation, in which we use the first part of a video entitled “Fraunhofer Diffraction-Multiple Slits” in MIT Open Couse Ware [19].
c. Diffraction Grating Experiment with Variation of Grating Constant, in which we use the second part of a video entitled “Fraunhofer Diffraction-Multiple Slits” in MIT Open Couse Ware [19].

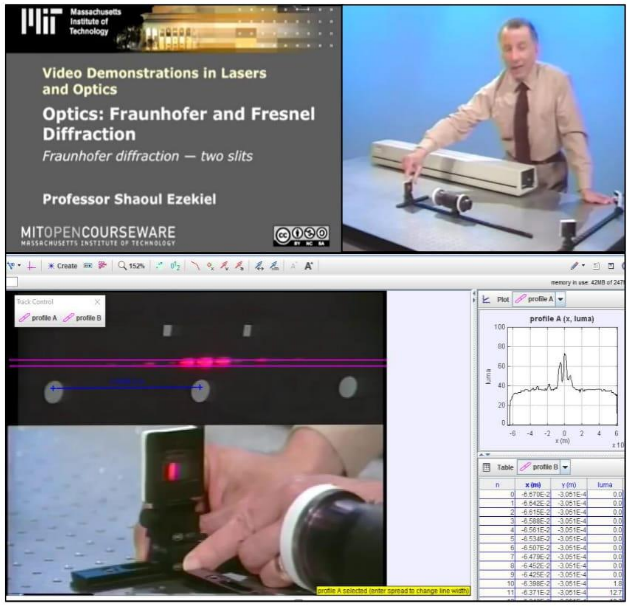

Figure 1. (a) Fraunhofer diffraction experiment presented on MIT Open Courseware video demonstration. (b) Diffraction pattern analysis using Video *Tracker* Software

RESULTS

Double Slits Experiment with Slit Spacing Variation

In the experiment with double slits, the slit spacing is adjusted then the diffraction spectra are analyzed. The slit spacing is varied to be 150, 200, and 300 μm. The diffraction pattern obtained from analysis with *Tracker* is depicted in Fig. 2. Using the same parameters with the experiment ($L = 2$ m, $d = 100\mu$m, and $\lambda = 6328$ Å), we plot the diffraction pattern at double slit according to Eq (1) (see Fig. 3).

The experimental pattern is not as smooth as the theoretical pattern. It may be due to the limitation in the experiment itself or the limitation of the imaging technique. However, qualitatively the experimental pattern shows a similar pattern with the theoretical intensity profile for the diffraction at the double slits. As the slit spacing increases, the width of the central and nearby maxima becomes narrower. The location of the first and second maxima also shifts closer to $\theta = 0$, as the slit spacing increases.

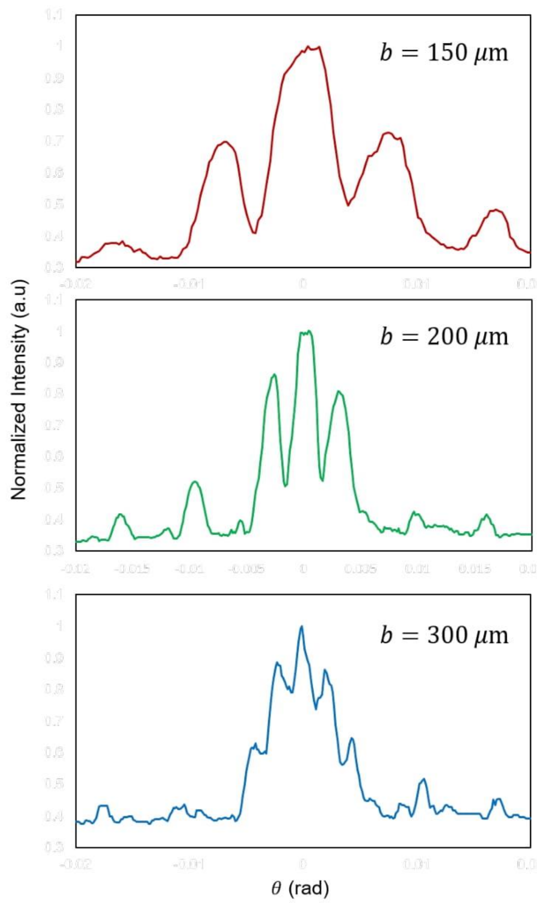

Figure 2. Experimental double slits diffraction pattern with various slit spacing. In the experiment, the distance between the slit and the screen (L) is fixed, 2 m. The slit width (d) used is 100 μm. The laser used is helium laser with $\lambda = 6328$ Å.

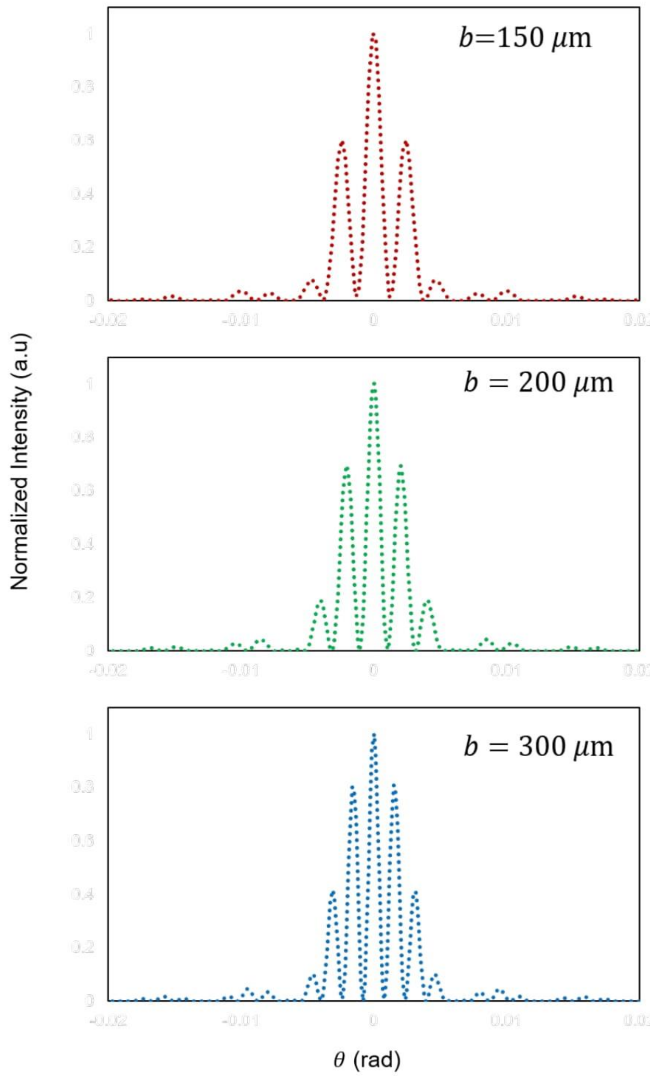

Figure 3. Theoretical double-slit diffraction pattern with various slit spacing. The used parameters are $L = 2$ m, $d = 100\mu$m, and $\lambda = 6328$ Å

Multiple Slits Experiment with Number of Slits Variation

For multiple slits experiments, the number of slits (N) is varied. The slit width (d) and spacing (b) are fixed to 50 and $75\ \mu$m, respectively. Fig. 4 shows the diffraction pattern obtained from video analysis with *Tracker*. Whereas Fig. 5 shows the diffraction pattern got theoretically by plotting Eq. (1) with the same parameters used in the experiment ($L = 2$ m, $d = 50\mu$m, $b = 75\ \mu$m, and $\lambda = 6328$ Å).

Similar to the double-slit experiment result, the experimental diffraction patterns at multiple slits are also not as smooth as the theoretical prediction. However, the same trend is observed. As the number of slits increases, the width of the maxima becomes narrower. For $N > 2$, small peaks/small maxima arise between principal maxima.

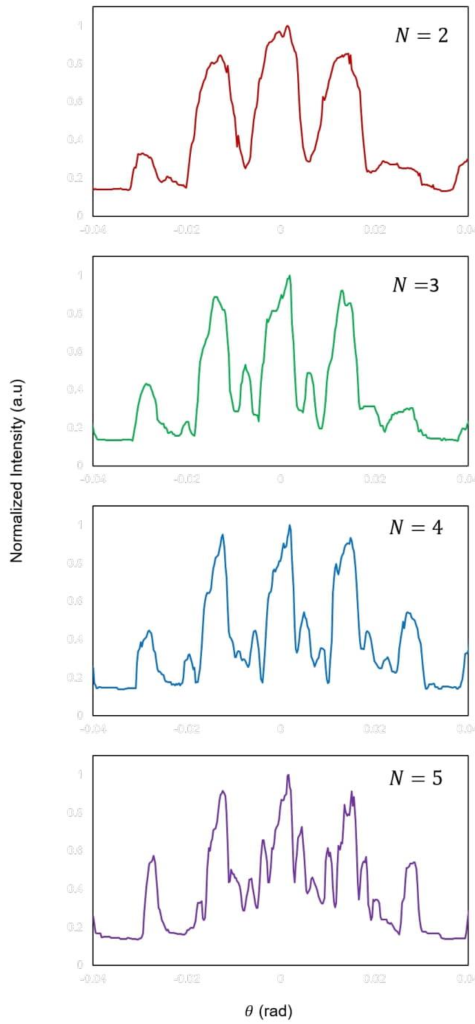

Figure 4. Experimental diffraction pattern with various slits number. In the experiment, the distance between the slit and the screen (L) is fixed, 2 m. The slit width (d) and the slit spacing (b) used are 50 and 75 μm, respectively. The laser used is helium laser with $\lambda = 6328$ Å.

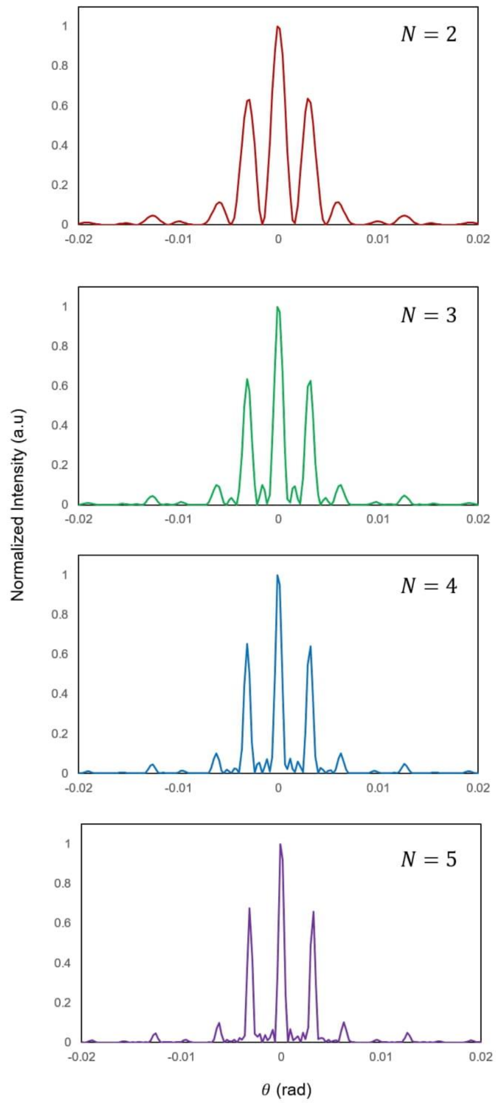

Figure 5. Theoretical diffraction pattern with various slits number. The used parameters are $L = 2$ m, $d = 50\mu$m, $b = 75$ μm, and $\lambda = 6328$ Å

Diffraction Grating Experiment with Variation of Grating Constant

The experiment is continued with diffraction grating. In this experiment, the grating constant is varied. The used grating constants are 100, 200, and 300 lines/inch. The intensity of the Fraunhofer diffraction pattern is presented in Fig. 6. It can be seen that as the grating constant increases, the distance between principal maxima or fringe spacing become wider. By using the intensity profile in Fig. 6 and Eq. (3) , we also can determine the wavelength of the laser. The calculated wavelength from the experiment is $6.160 \pm 0.037 \times 10^{-7}$ m (see Table 1). This value is slightly below the reference value (λ_{ref} =6.328× 10^{-7} m) that is given in the video explanation. The percentage of discrepancy between the result of the laser wavelength found with *Tracker* and the reference value given in the video is about 2.6%; which is quite small.

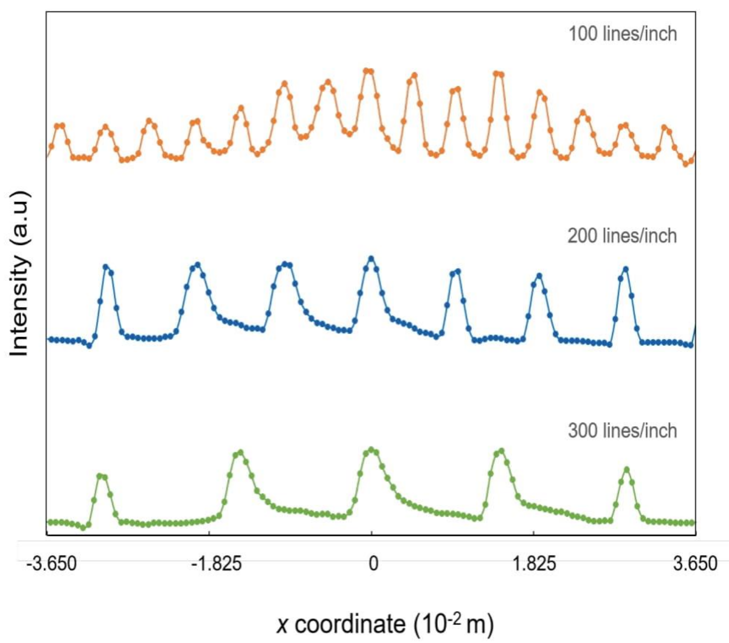

Figure 6. Intensity profile of Fraunhofer Diffraction By Grating with various grating constant

Tabel 1. Wavelength Calculation

L (m)	Δ (x 10^{-4} m)	n	S_n (m)	λ (x 10^{-7} m)
2	2.540	1	0.0048	6.096
2	1.270	1	0.0098	6.223
2	0.847	1	0.0146	6.181
$\bar{\lambda} = 6.160 \pm 0.037 \times 10^{-7}$ m				
$\%\text{discrepancy} = \frac{\lvert\bar{\lambda} - \lambda_{ref}\rvert}{\lambda_{ref}} \times 100\% = 2.6\%$				

IMPLEMENTATION IN LEARNING PROCESS

In distance learning, laboratory activity is hard to be conducted. Activity with video analysis and spreadsheets can be an alternative option. Through the activity, students can develop their science process skills and conceptual understanding in Fraunhofer diffraction. They also can improve mathematical and computational thinking skills.

In the teaching and learning process, the teacher can begin by presenting the Fraunhofer Diffraction video demonstration from MIT Open CourseWare. Meanwhile, students are asked to observe the Fraunhofer diffraction phenomena in the video. After the observation, the teacher can ask students to analyze the light spectra using the *Tracker*. However, teachers need to give an introduction to *Tracker* beforehand. After students get some findings, they should present their findings in the class forum. The activity can be continued with a discussion of Fraunhofer Diffraction through a mathematical approach. The teacher can encourage students to visualize the obtained mathematical equation with the spreadsheet. The discussion may enrich students with a theoretical explanation about their observation.

The video analysis activity can be carried out as a project or homework. This learning scenario will engage students more in ‘virtual’ physics experiments, and students may become more motivated in learning physics.

CONCLUSION

In this paper, we have presented the investigation of Fraunhofer diffraction with double and multiple slits through *Tracker* and *spreadheet* program. Learning Fraunhofer diffraction using video *Tracker* and spreadsheet enables students to compare experimental and theoretical results. This activity has the potential to be used in distance learning to accommodate laboratory-related physics course.

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6.	**Bukti konfirmasi artikel accepted**	**17 Juli 2020**

Gmail Elisabeth Founda <elisa.founda@gmail.com>

[RMF E] Editor Decision

3 messages

Prof. Alejandro Ayala <rmf@ciencias.unam.mx> Wed, Jun 17, 2020 at 7:58 PM
To: "Ms. Elisabeth FOUNDA Pratidhina" <elisa.founda@gmail.com>

Dear Ms Elisabeth FOUNDA Pratidhina:

We are pleased to inform you that your paper titled: "Exploring Fraunhofer Diffraction Through Tracker and Spreadsheet: An Alternative Lab Activity for Distance Learning", has been accepted for publication in Revista Mexicana de Física E.

Comments from the referee are enclosed for your information.

Sincerely,

Prof. Alejandro Ayala
Chief Editor
Revista Mexicana de Física

____

Reviewer A:

Dear Editor and Authors,
after the revised versions of the author's original paper, I am very pleased with the changes and the final result. Therefore I recommend the paper's publication.

Best regards.

____
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Thank you in advance.

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Revista Mexicana de Física.

Elisabeth Founda <elisa.founda@gmail.com> Jun 24, 2020, 8:42 AM
to Revista

Dear Prof Alejandro Ayala,

Thank you for your email. I attach the required files, such as manuscript in word format and figures in this email

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With sincere regards,

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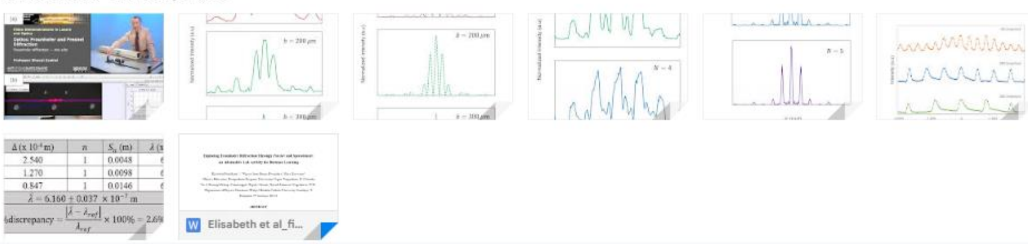
8 Attachments • Scanned by Gmail



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We thank you in advance for your understanding.

Sincerely,
Editorial Team
Revista Mexicana de Física.

...

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Exploring Fraunhofer diffraction through Tracker and spreadsheet: An alternative lab activity for distance learning

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Keywords: Fraunhofer diffraction, Tracker, Spreadsheet, Distance Learning

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EDUCATION Revista Mexicana de Física E **17** (2) 285–290 JULY–DECEMBER 2020

Exploring Fraunhofer diffraction through *Tracker* and spreadsheet: An alternative lab activity for distance learning

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Received 30 May 2020; accepted 17 June 2020

In this paper, we present an alternative for physics laboratory activity related to Fraunhofer diffraction in distance learning. The activity utilizes a demonstration video from MIT Open CourseWare, *Tracker* software, and spreadsheet. An online demonstration video is used because it is the most accessible resource during undesirable conditions such as COVID 19 pandemic. In the activity, students can explore diffractions phenomena with multiple slits. The effect of slit spacing and slit numbers to the intensity of light is investigated trough spectral analysis with *Tracker*. The investigation is followed by a discussion through the mathematical approach and visualization with spreadsheets. It will enrich students with a theoretical explanation of the observation. This distance learning activity allows students to develop their science process skills, mathematical and computational thinking skills, and conceptual understanding of Fraunhofer diffraction.

Keywords: Fraunhofer diffraction; Tracker; spreadsheet; distance learning.

PACS: 01.40.-d DOI: https://doi.org/10.31349/RevMexFisE.17.285

1. Introduction

Recently, distance learning and blended learning are popular. Notably, during the undesirable pandemic, the governments, school principals, and teachers are forced to change traditional classrooms into the digital classes. In a short time, teachers have to think about how to teach their students effectively in distance learning mode. One efficient way is to use existing resources and technologies.

For physics teachers, the challenge is migrating lab activities to the digital model. Several experiment resources are available online; one of them is Demonstrations in physical optics provided by MIT Open Course Ware [1]. The resources include various demonstrations about optical phenomena such as polarization, diffraction, and propagation in optical fiber. That kind of resource can be used to teach physics in distance learning mode. Instead of taking data by hands-on measurement, students can take data by video analysis using software such as *Tracker*.

Tracker is useful and free software in physics education, which is developed on the Open Source Physics Java code library. People use it for video analysis and physics modeling. By using *Tracker*, users can track an object's position, velocity, and accelerations [2]. It also has a calibration feature to calibrate the length quantity in the video to the real one. Moreover, the RGB line profile feature in *Tracker* can be used to analyze spectra.

Tracker has been used for pedagogical purposes and complex physics experiments. Educators and scientist use *Tracker* to teach and study various topics such as vector object falling in liquid and air [3], projectile motion [4,5], mechanical energy [6], kater pendulum [7], damped harmonic oscillation [8], torsion [9], impulse [10], astronomy [11], and optical geometry [12]. *Tracker* is a potential tool to promote and guide the student as a scientist. Students can explore the laws of nature with *Tracker*. By using video modeling, students can practice to ask questions, use models, and develop mathematical and computational thinking [13]. It also encourages students to think creatively and improve their physics learning performance [14].

Spreadsheets such as Ms. Excel are powerful computing and graphical tools. In physics education, we can build simple simulations and visualization in the spreadsheet when we are discussing a physics equation [15,16].

In this work, we present the use of these two didactic tools, *i.e.*, *Tracker* and spreadsheet, for a distance learning activity in physics. We utilize *Tracker* to analyze the Fraunhofer diffraction pattern at double and multiple slits. Instead of record a video from a direct experiment, we use the available demonstration video resources from MIT Open Course Ware. Then, the observed pattern from *Tracker* analysis is compared to the theory by utilizing the spreadsheet program, *Ms. Excel*.

2. Theory of diffraction

Phenomena that can prove the wave nature of light is diffraction. It occurs when a wavefront portion is obstructed in some way or encounters one (or many) slits, and the wavefront is altered in amplitude or phase. Segments of wavefront which propagate beyond the obstacle interfere and construct diffraction pattern [17]. There are two kinds of diffractions, *i.e.*, Fresnel diffraction and Fraunhofer diffractions. In Fraunhofer diffraction, the incoming and outgoing waves approach must be planar over the extent of the obstacles. Fraunhofer diffraction occurs when the distance between the obstacle and the screen is far enough.

The obstacles for Fraunhofer diffraction can be a single slit, double slits, and multiple slits. The multiple slits can be a diffraction grating. For Fraunhofer diffraction at N parallel slits, the intensity distribution is given by Eq. (1).

$$I(\theta) = I_0 \left(\frac{\sin\beta}{\beta}\right)^2 \left(\frac{\sin N\alpha}{\sin\alpha}\right)^2, \tag{1}$$

with,

$$\alpha \equiv \frac{\pi(b+d)\sin\theta}{\lambda},$$

$$\beta \equiv \frac{\pi d}{\lambda}\sin\theta,$$

where d is the slit width, b is the slit spacing, λ is the wavelength of the light, θ is the observation angle, and I_0 is the intensity of the center maxima, *i.e.*, the intensity in the $\theta = 0$ rad.

In Fraunhofer diffraction with multiple slits, there are regularly spaced principal maxima, and some smaller maxima which lay in between the principal maxima. The principal maxima spacing on the screen follows relation:

$$\sin\theta_n = \frac{n\lambda}{S_n}, \quad n = 0, \pm 1, \pm 2, ... \tag{2}$$

By using approximation $\sin\theta_n \approx (\Delta/L)$, Eq. (2) can be written as:

$$S_n = \frac{Ln\lambda}{\Delta}, \tag{3}$$

where S_n is the fringe spacing on the screen, L is the distance between the slit and the screen, λ is the wavelength, Δ is the slit separation, and n is an index of the maxima. For diffraction grating, slit separation can be calculated from $\Delta = (1/\text{grating constant})$.

3. Method

We use the Fraunhofer diffraction demonstration video available in MIT Open Couse Ware [1]. The diffraction pattern in the video is analyzed by using *Tracker* software. *Tracker* software allows tracking line profiles, which give the data about intensity (luma) at specific points. *Tracker* also allows calibration to match the dimension, such as length, in the video to the real dimension. Figure 1 shows how the setup of *Tracker* looks like.

When we start video analysis in *Tracker*, we have to import the video by selecting File > Import > Video; then we choose the video that we want to analyze. For calibration, we need to select Track Menu > New > Calibration Tool > Calibration Stick. We can mark two calibration points by using a shifting keyboard and click. After two points are marked, we have to input the actual distance of those two points. By doing this, the length of objects in the video has been calibrated to their actual length. For intensity analysis, we need to choose Track Menu > New > Line Profile. We can select the region which we want to analyze by pressing shift keyboard and mouse click. The line region can be expanded by mouse click and drag. The intensity and position data will be presented as a graph and table on the right side of the *Tracker* program.

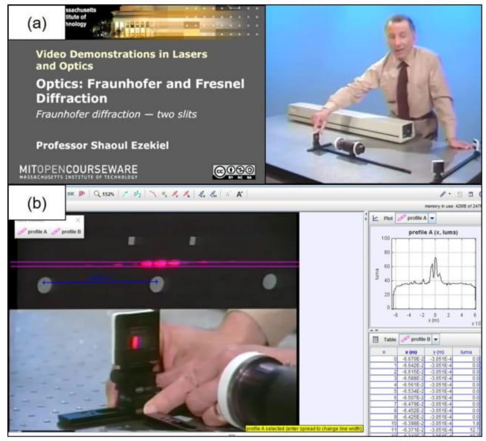

FIGURE 1. (a) Fraunhofer diffraction experiment presented on MIT Open Courseware video demonstration. (b) Diffraction pattern analysis using Video *Tracker* Software.

After we get the data about point position and intensity in *Tracker*, we bring them to a spreadsheet program to plot the spectra. Then, we plot Eq. (1) with the given parameters in the experiment to provide a theoretical comparison. In this work, we conducted 3 investigations, *i.e.*

a. Double Slits Experiment with Slit Spacing Variation, in which we use a video entitled "Fraunhofer Diffraction-Two Slits" in MIT Open Couse Ware [18].

b. Multiple Slits Experiment with Number of Slit Variation, in which we use the first part of a video entitled "Fraunhofer Diffraction-Multiple Slits" in MIT Open Couse Ware [19].

c. Diffraction Grating Experiment with Variation of Grating Constant, in which we use the second part of a video entitled "Fraunhofer Diffraction-Multiple Slits" in MIT Open Couse Ware [19].

4. Results

4.1. Double slits experiment with slit spacing variation

In the experiment with double slits, the slit spacing is adjusted then the diffraction spectra are analyzed. The slit spacing is varied to be 150, 200, and 300 μm. The diffraction pattern obtained from analysis with *Tracker* is depicted in Fig. 2.

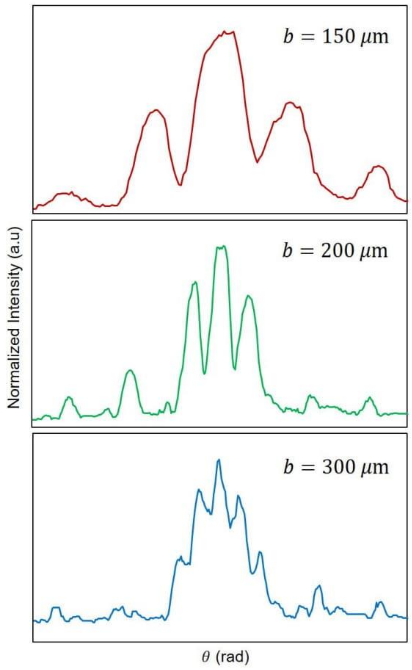

FIGURE 2. Experimental double slits diffraction pattern with various slit spacing. In the experiment, the distance between the slit and the screen (L) is fixed, 2 m. The slit width (d) used is 100 μm. The laser used is helium laser with $\lambda = 6328$ Å.

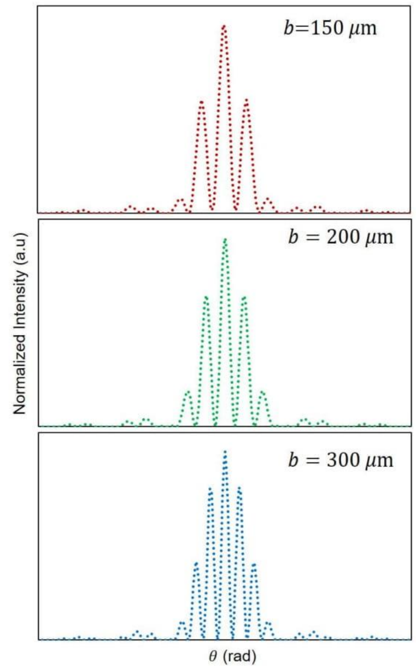

FIGURE 3. Theoretical double-slit diffraction pattern with various slit spacing. The used parameters are $L = 2$ m, $d = 100$ μm, and $\lambda = 6328$ Å.

Using the same parameters with the experiment ($L = 2$ m, $d = 100$ μm, and $\lambda = 6328$ Å), we plot the diffraction pattern at double slit according to Eq. (1) (see Fig. 3).

The experimental pattern is not as smooth as the theoretical pattern. It may be due to the limitation in the experiment itself or the limitation of the imaging technique. However, qualitatively the experimental pattern shows a similar pattern with the theoretical intensity profile for the diffraction at the double slits. As the slit spacing increases, the width of the central and nearby maxima becomes narrower. The location of the first and second maxima also shifts closer to $\theta = 0$, as the slit spacing increases.

4.2. Multiple slits experiment with a variation of slits number

For multiple slits experiments, the number of slits (N) is varied. The slit width (d) and spacing (b) are fixed to 50 and 75 μm, respectively. Figure 4 shows the diffraction pattern obtained from video analysis with *Tracker*. Whereas Fig. 5 shows the diffraction pattern got theoretically by plotting Eq. (1) with the same parameters used in the experiment ($L = 2$ m, $d = 50$ μm, $b = 75$ μm, and $\lambda = 6328$ Å).

Similar to the double-slit experiment result, the experimental diffraction patterns at multiple slits are also not as smooth as the theoretical prediction. However, the same trend is observed. As the number of slits increases, the width of the maxima becomes narrower. For $N > 2$, small peaks/small maxima arise between principal maxima.

4.3. Diffraction grating experiment with a variation of grating constant

The experiment is continued with the diffraction grating. In this experiment, the grating constant is varied. The used grating constants are 100, 200, and 300 lines/inch. The intensity of the Fraunhofer diffraction pattern is presented in Fig. 6. It can be seen that as the grating constant increases, the distance between principal maxima or fringe spacing become wider. By using the intensity profile in Fig. 6 and Eq. (3), we also can determine the wavelength of the laser. The calculated wavelength from the experiment is $6.160 \pm 0.037 \times 10^{-7}$ m (see Table I). This value is slightly below the reference value ($\lambda_{ref} = 6.328 \times 10^{-7}$ m) that is given in the video explanation. The percentage of the discrepancy between the result of the laser wavelength found with *Tracker*, and the reference value is given in the video is about 2.6%; which is quite small.

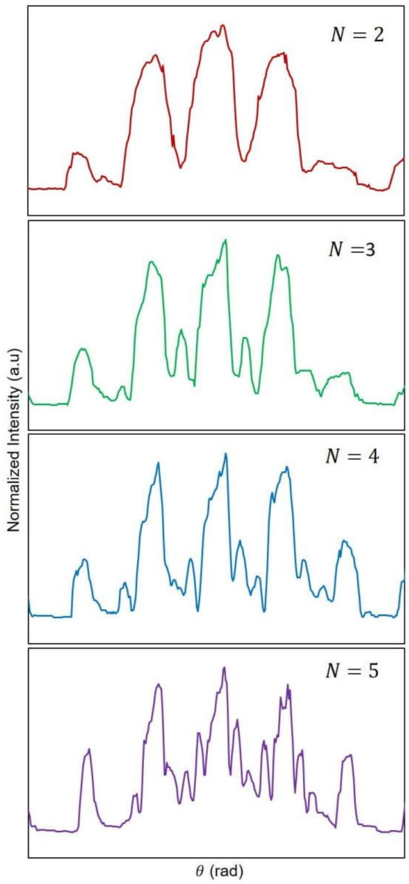

FIGURE 4. Experimental diffraction pattern with various slits number. In the experiment, the distance between the slit and the screen (L) is fixed, 2 m. The slit width (d), and the slit spacing (b) used are 50 and 75 μm, respectively. The laser used is helium laser with $\lambda = 6328$ Å.

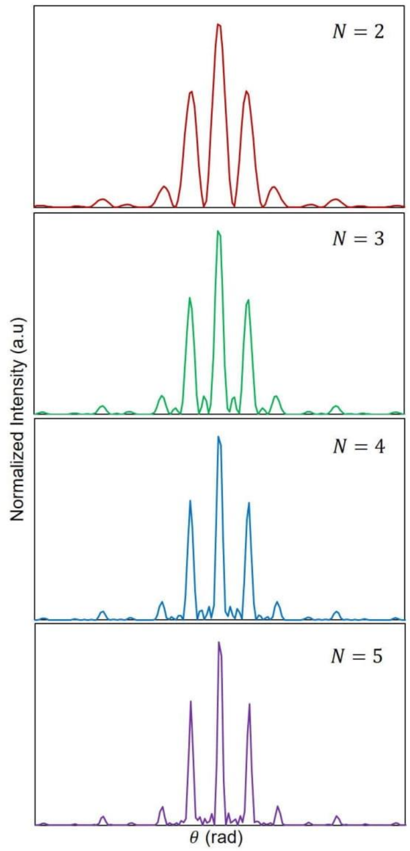

FIGURE 5. Theoretical diffraction pattern with various slits number. The used parameters are $L = 2$ m, $d = 50$ μm, $b = 75$ μm, and $\lambda = 6328$ Å.

4.4. Implementation in learning process

In distance learning, laboratory activity is hard to be conducted. Activity with video analysis and spreadsheets can be an alternative option. Through the activity, students can develop their science process skills and conceptual understanding in Fraunhofer diffraction. They also can improve mathematical and computational thinking skills.

In the teaching and learning process, the teacher can begin by presenting the Fraunhofer Diffraction video demonstration from MIT Open CourseWare. Meanwhile, students are asked to observe the Fraunhofer diffraction phenomena in the video. After the observation, the teacher can ask students to analyze the light spectra using the *Tracker*. However,

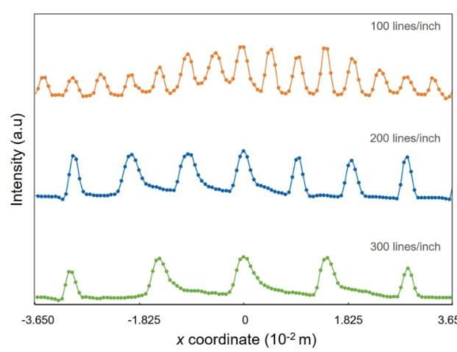

FIGURE 6. Intensity profile of Fraunhofer diffraction by grating with various grating constant.

TABLE I. Wavelength Calculation

L (m)	$\Delta(\times 10^{-4}$ m)	n	S_n (m)	$\lambda(\times 10^{-7}$ m)
2	2.540	1	0.0048	6.096
2	1.270	1	0.0098	6.223
2	0.847	1	0.0146	6.181
$\bar{\lambda} = 6.160 \pm 0.037 \times 10^{-7}$ m				
%discrepancy $= (\lvert\bar{\lambda} - \lambda_{\text{ref}}\rvert/\lambda_{\text{ref}}) \times 100\% = 2.6\%$				

teachers need to give an introduction to *Tracker* beforehand. After students get some findings, they should present their findings in the class forum. The activity can be continued with a discussion of Fraunhofer Diffraction through a mathematical approach. The teacher can encourage students to visualize the obtained mathematical equation with the spreadsheet. The discussion may enrich students with a theoretical explanation about their observation.

The video analysis activity can be carried out as a project or homework. This learning scenario will engage students more in 'virtual' physics experiments, and students may become more motivated in learning physics.

5. Conclusion

In this paper, we have presented the investigation of Fraunhofer diffraction with double and multiple slits through *Tracker* and *spreadsheet* program. Learning Fraunhofer diffraction using video *Tracker* and *spreadsheet* enables students to compare experimental and theoretical results. This activity has the potential to be used in distance learning to accommodate laboratory-related physics course.

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