Supplementary Material
Evaluation of the course Machine Learning for All!

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Acronyms and Abbreviations

AI	Artificial Intelligence
AP	Application
CS	Computer Science
HS	High school
INCoD	National Institute of Science and Technology for Digital Convergence
LO	Learning objective
ML	Machine Learning
MS	Middle school
UFSC	Universidade Federal de Santa Catarina

Summary

1. Overview

Machine Learning for All (a.k.a ML4ALL) is an interdisciplinary online course for teaching Machine Learning (ML) to novices in middle and high school. This course was applied and evaluated through a series of case studies in order to evaluate its effect on student learning and learning experience. The course development and evaluation are presented in (Martins et al., 2022). This document presents supplementary material of the results presented in the article.

2. Details on the state of the art

Based on systematic literature reviews as part of earlier research (Marques et al., 2020; Martins and Gresse von Wangenheim, 2022) instructional units teaching ML in middle and high school have been identified (Table 1).

Table 1. Instructional units teaching ML in middle and high school

References	Quality factor evaluated	Main Findings
(Apps for Good, 2019)	Understanding	NI
(Bhatia, 2020)	Understanding	Improved understanding of what ML is and how it works; students enjoyed exploring and building their own classification applications.
(Bilstrup *et al.*, 2020)	Engagement; Understanding	Students were able to design a system that (in a basic way) addressed ML system
(Burgsteiner *et al.*, 2016a) (Burgsteiner, 2016b)	Understanding; Interest; Self-motivation	Pupils got a well founded understanding of those concepts and the growing importance of AI High self-motivation from students
(Chua *et al.*, 2019)	Interest; Enthusiasm	Students demonstrated a high level of understanding of the course content. Students demonstrated creativity in applying the learned skills to new data
(CS4FN, 2011)	Understanding	NI
(Essinger and Rosen, 2019)	Understanding	NI
(Estevez *et al.*, 2019)	Understanding	Students have acquired the confidence to be able to understand the workings of AI algorithms
(Evangelista *et al.*, 2018)	Understanding	NI
(Fryden, 2019)	Learning	NI
(Grillenberger and Romeike, 2019)	Interest; Motivation	The course was able to show that data science topics (including ML), often thought of as complex, can be reduced and addressed in teaching at the lower secondary level without having to abstract too much from the core aspects.
(Huang *et al.,* 2021)	Understanding; Interest	Students enjoyed project-based learning with hands-on sections building a medical AI workflow rather than just learning knowledge from textbooks
(Kandlhofer *et al*., 2016)	Motivation; Learning; Expectation	Students got a well founded understanding of almost all AI literacy topic
(Kandlhofer *et al.*, 2019)	Learning	Student-centered approach is, in general, an appropriate method to achieve the educational goals of this project
(Kaspersen *et al.*, 2021)	Understanding	Demonstrates the qualities of an iterative approach for engaging students in understanding and reflecting about ML
(Lao, 2020)	Understanding	The course increased the feeling about explaining and discussing ML. The most fun part of the workshop was about taking pictures of their own facial expressions (for classification)
(Mariescu-Istodor and Jormanainen, 2019)	Interest; Enjoyment; Effort; Importance;	The experience of running the tutorial has shown that the collaborative work approach suits high school students, and they are able to come up with new and unexpected ideas.
(Mike *et al.*, 2020)	NI	Discuss helped them refine the formulation of their own project topics
(MIT, 2019)	NI	NI
(Mobasher *et al.*, 2019)	Interest and commitment.	More than 90% of the participants agreed: that they understood classification methods
(Narahara and Kobayashi, 2018)	NI	NI
(Neumann, 2019)	Sentiment and Understanding	Students understand basic Python processes to handle data, implement and apply simple learning models, and visualize and interpret their result
(Norouzi *et al*., 2020)	Perception; Interest; Learn; Understand, Motivation; Use in the future; Gender satisfaction	The combination objectivist and constructivist curriculum designed was successful in providing students with a more in-depth understanding of AI and helped them in being more realistic and explicit about the tasks that AI can be used for.
(ReadyAI, 2019)	NI	NI
(Rodríguez-Garcia *et al.*, 2021)	Perception	Young people are able to learn about AI.

(Rodríguez-Garcia, *et al*., 2019)	Involvement	AI-related contents can be embraced in K-12
(Santana *et al*., 2018)	Engagement	Students demonstrated knowledge about project execution. Results are positive in 3 dimensions (Behavioral, Emotional and Cognitive) for 4 activities (Context, Problem, Data collection and Data analysis).
(Sakulkueakulsuk *et al*., 2018)	Learning	NI
(Sperling and Lickerman, 2012)	Learning	Students feel confident when solving a problem (overcome the difficulties). Motivated the students to continue research in AI and ML content according to their ability
(Tang *et al*., 2019)(Tang, 2019)	Learning; Experience; Understanding	Results show that the tools have the potential to be a valuable asset in ML education. For an audience of high schoolers with no experience in ML, the tools that we built were very helpful in introducing ML concepts.
(TechGirlz, 2018)	NI	NI
(Vachovsky *et al*., 2016)	Interest	Students reported confidence in their projects. Students found a sense of community in AI and computer science. Increased the students' interest in CS, AI studies and AI career in the future.
(Van Brummelen, 2019; Van Brummelen, *et al*., 2020)	Engagement; Understanding; Comfort	Students were comfortable developing conversational AI applications.
	Improvements;Evidence for Learning;	Hands-on, interactive activities, and leveraging learners' interests contributed to high engagement. Students' favorite part of the workshops was programming
(Voulgari *et al*., 2021)	Enjoyment; Understanding	Students enjoyed that they had to think of the appropriate strategies and "use their brain. The game-based helped students understand what machine learning is
(Wan *et al*., 2020)	Learning	The tool (SmileyCluster) supported participants' learning of key ML knowledge components of k-means cluster. Participants collaboratively worked on the tasks.
(Zhu, 2019)	Learning	Students had a stronger understanding of machine learning (demonstrating that the class helped them learn the subject).
(Zimmermann-Niefield *et al*., 2019)	Learning	Participants made hypotheses about the performance and validity of their ML models. Participants made hypotheses about the performance and validity of their models.

NI: Not identified/Not informed

3. Details on the application of the course

The course has been applied in 5 cases in middle school and high school as presented in Table 2.

Table 2. Participant Demographics

Number of Participants					
		Educational stages		Gender	
Application	Participants	Middle School (≤ 15 y)	High School (>15 y)	Female	Male
AP1	12	9 (75.00%)	3 (25.00%)	3 (25.00%)	9 (75.00%)
AP2	10	1 (10.00%)	9 (90.00%)	6 (60.00%)	4 (40.00%)
AP3	35	9 (25.71%)	26 (74.29%)	9 (25.71%)	26 (74.29%)
AP4	40	6 (15.00%)	34 (85.00%)	16 (40.00%)	24 (60.00%)
AP5	11	6 (54.55%)	5 (45.45%)	*	*
Total	108	33 (29.4%)	80 (71.4%)	36 (35.64%)†	65 (64.36%)†

*Information on gender was not collected as part of AP5
†Considering AP1 - AP4

3.1 Data collection

Based on the analysis questions, data collection items were defined following the dETECT model (Gresse von Wangenheim et al. 2017) as presented in Table 3.

Table 3. Data collection plan

Analysis question	Based on	Data collection instrument	Quality factor	Data collection items	Response scale
AQ1	Learning outcomes LO1 to LO7	Quiz questions per class	Learning	Quiz responses class 1. motivation Quiz responses class 2. basic concepts Quiz responses class 3. data preparation Quiz responses class 4. model training Quiz responses class 5. ML process Quiz responses class 6. ethical issues and opportunities	Continuous scale (range 0-10 points)
	Learning outcomes LO3 to LO5	Report 1. C1-C5 Report 2. C6 Report 3. C7-C11	Learning	Dataset Model .tm Test results Accuracy analysis Results interpretation Adjustments improvements	3-point ordinal scale
AQ1	Student's perception of learning	Feedback questionnaire	Learning	I understand what ML is I can develop a ML model for image recognition Developing an ML model is? I can explain to a friend what ML is	Yes, no Yes, no 5-point ordinal scale
AQ2	Student's perception of learning	Feedback questionnaire	Enjoyability	The course was? The course was? Class time has passed? I want to learn more about ML	5-point ordinal scale 5-point ordinal scale 5-point ordinal scale Yes, no
			Overall quality of the course	Overall the course was? What else did you like about the course? What did you like least about the course?	5-point ordinal scale Open text Open text

Data were collected from students during the applications of the course through quizzes and reports on the development of the ML model. At the end of the course the students' feedback was collected through a post-questionnaire (Table 4).

Table 4. Overview on the collected data

Application	**No of quiz responses per class**						**No of reports submitted for performance-based assessment**			**No of feedback questionnaires**
	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Report 1.C1-C5	Report 2. C6	Report 3. C7-C11	Feedback
AP1	6	10	8	10	10	10	12	12	12	11
AP2	6	5	8	8	4	4	9	9	9	7
AP3	17	20	35	33	29	28	35	25	35	30
AP4	34	32	36	32	29	29	31	31	31	34
AP5	–	–	–	–	–	–	–	–	–	11
Total	63	67	87	82	72	71	87	77	87	93

4. Details on the analysis

Regarding the research questions, the detailed analysis results are presented in this section.

4.1 Student Learning: Are the learning objectives achieved and are there differences with respect to educational stage, gender, or instructional mode?

Analyzing student learning based on the interactive quizzes, Figure 1 presents the mean quiz scores summarized per educational stages (middle school and high school), gender (female and male) and instructional mode (face-to-face in AP1 and remote instructor-paced in AP2-AP4).

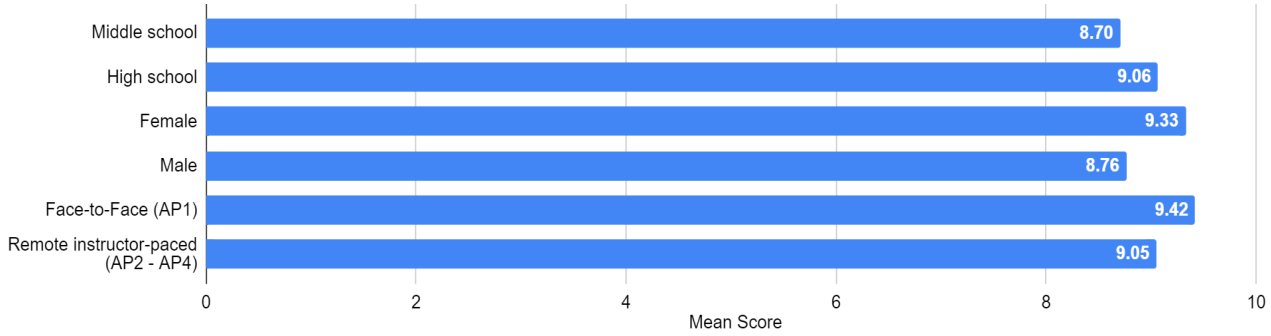


Figure 1. Mean quiz scores per educational stage, gender and instructional mode

Completing the evaluation of student learning through a performance-based evaluation according to the ML rubric - image classification (Gresse von Wangenheim et al., 2021), the learning results created by the students in class 3 and 4 developing an ML model for the image classification task in relation to learning objectives LO3 - LO4 are analyzed. In addition, the interpretation of the performance of the ML model that the students created with respect to the learning objective LO5 is also assessed. Table 5 presents the median scores per educational stage, gender and instructional mode.

Table 5. Overview on the collected data

Comparison		**Poor (0 pt), Acceptable (1 pt), Good (2 pt)**										
		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
Educational stage	Middle School	2	2	1	1	2	1	2	2	0	2	1
	High School	2	2	2	1	2	1	2	2	2	2	1
Gender	Female	1	2	2	1	2	1	2	2	2	2	1
	Male	2	2	2	1	2	1	2	2	2	2	1
Instructional mode	Face-to-face (AP1)	2	2	2	2	0	1	2	1	0	0	1
	Remote instructor-paced (AP2 - AP4)	1	2	2	1	2	1	2	2	2	2	1

The students' perception of learning was analyzed based on their responses from the feedback questionnaire. Figure 2 shows the comparison of frequencies of responses of all applications per educational stage.

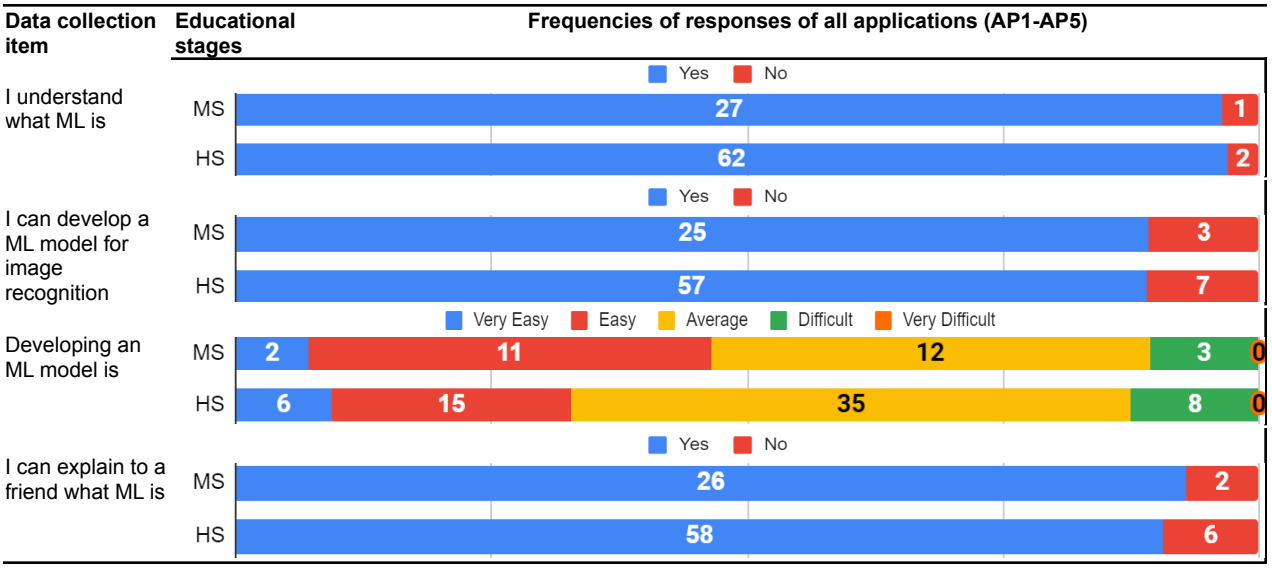


Figure 2. Frequencies of responses of all applications per educational stage

The students' perception of learning in all applications was also compared by gender (Figure 3).

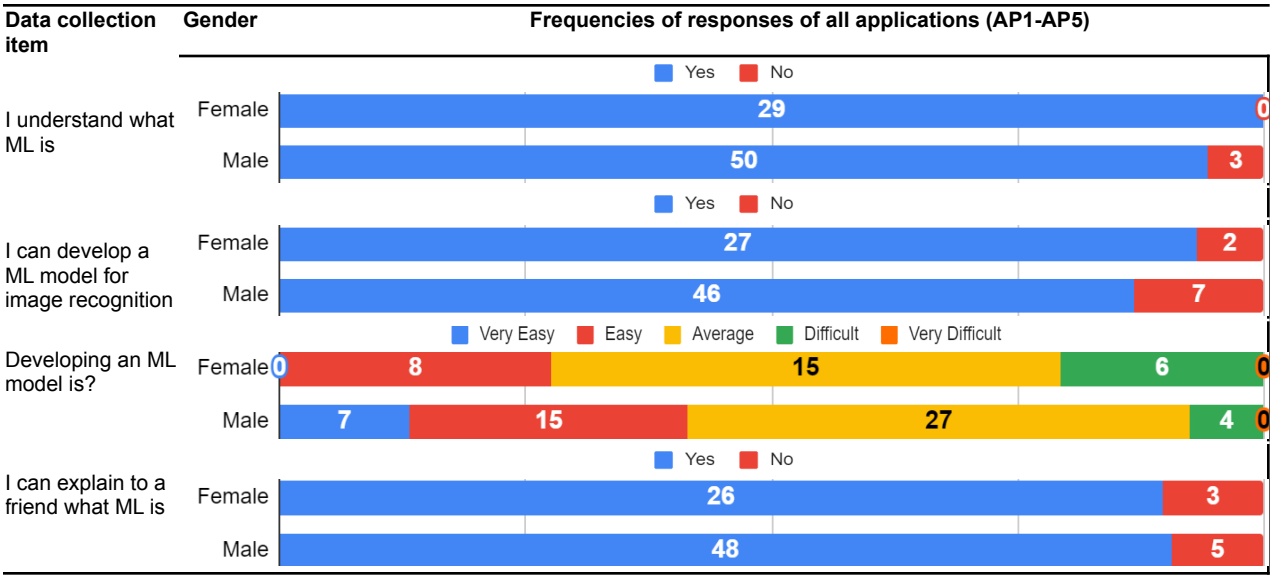


Figure 3. Frequencies of responses of all applications per gender

We analyzed the student's perception of learning with respect to the different instructional modes. We identified for each item the most frequent responses and the statistical mode of responses for the comparison per instructional mode (Table 6).

Table 6. Student's perception of learning compared per instructional mode

Data collection item	Mode and frequencies of responses					
	Face-to-face (AP1)		Remote instructor-paced (AP2 - AP4)		Remote as self-paced (AP5)	
	Mode	Frequency (%)	Mode	Frequency (%)	Mode	Frequency (%)
I understand what ML is	yes	72.73%	yes	100%	yes	100%
I can develop a ML model for image recognition	yes	63.64%	yes	92.96%	yes	90.91%
Developing an ML model is?	average	72.73%	average	47.89%	average	45.45%
I can explain to a friend what ML is	yes	54.55%	yes	95.77%	yes	90.91%

4.2 Learning Experience: Does the course promote a pleasant and enjoyable learning experience and are there differences with respect to educational stage, gender, or instructional mode?

The students' learning experiences were also extracted from their feedback given in the post-questionnaire. A comparison of frequencies of responses of all applications per educational stage is presented in Figure 4.

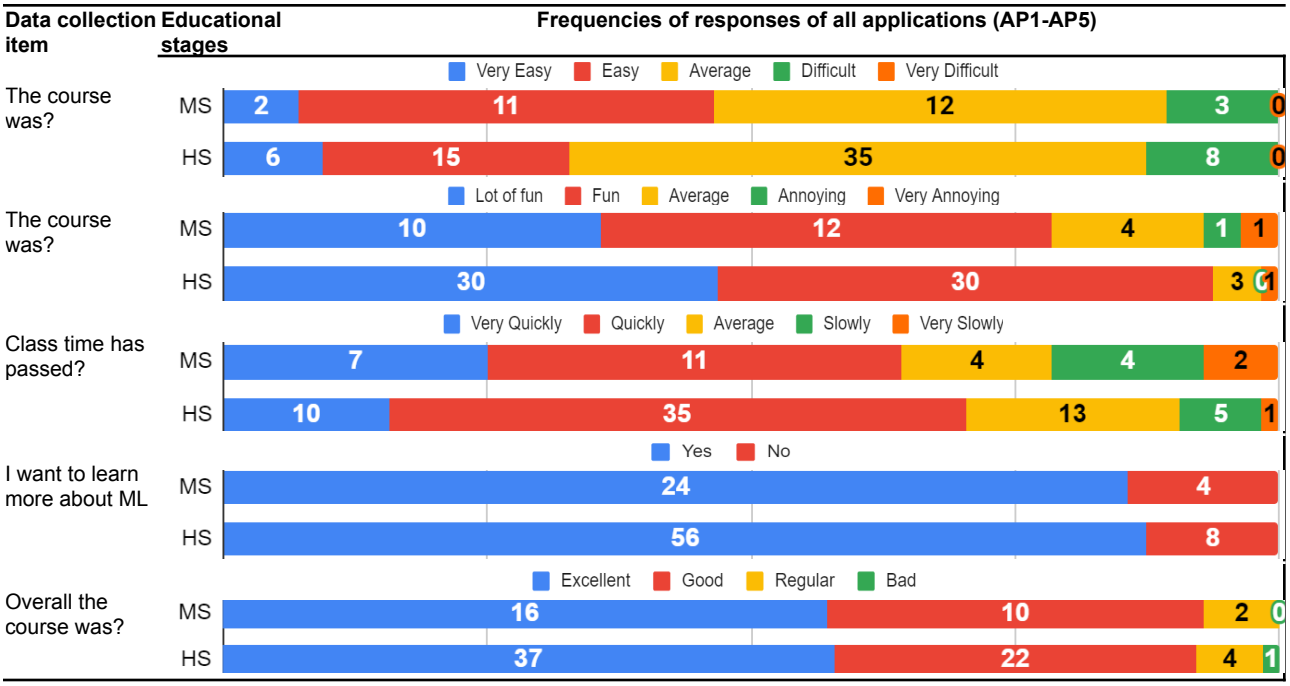
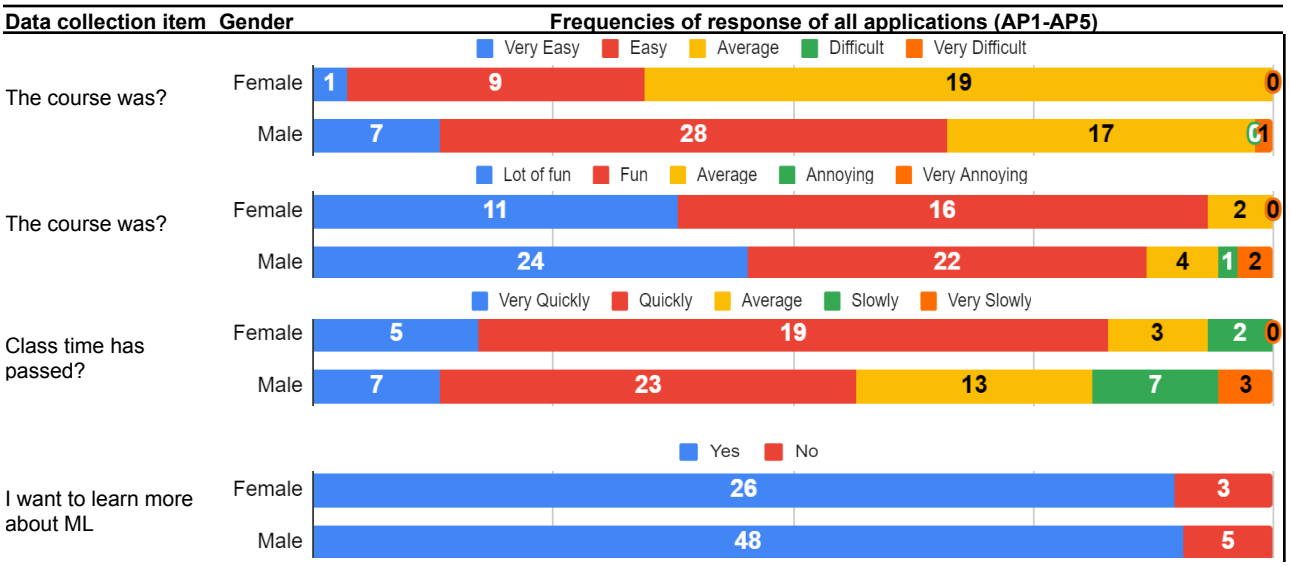


Figure 4. Frequencies of responses of all applications per educational stages

The students' learning experiences in all applications were also compared by gender (Figure 5).



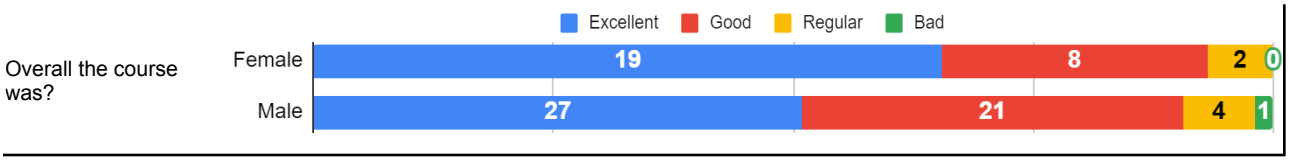


Figure 5. Frequencies of responses of all applications per gender

The student's learning experience in the different instructional modes was also analyzed regarding the course applications. We identified for each item in the collected data the most frequent responses and the statistical mode of responses for comparison of instructional modes (Table 6).

Table 6. Student's perception of learning per instructional mode

	Mode and frequencies of response					
Data collection item	**Face-to-face (AP1)**		**Remote instructor-paced (AP2 - AP4)**		**Remote as self-paced (AP5)**	
	Mode	(%)	Mode	(%)	Mode	(%)
The course was?	average	45.45%	easy	47.89%	easy	45.45%
The course was?	fun	54.55%	Lot of fun	49.30%	Lot of fun/fun	45.45%/45.45%
Class time has passed?	slowly	36.36%	quickly	54.93%	Very quickly	54.54%
I want to learn more about ML	no	63.64%	yes	92.96%	yes	100%

As part of the students' feedbackthe strengths (Table 7) and weaknesses (Table 8) of the course were also analyzed.

Table 7. Strengths of the course

What did you like most about the course?
the trainings
interesting
to work on the pc (3)
thinking (2)
to learn how to work in the course
everything (3)
I liked the Image Model activity.
I found it interesting to learn how to develop my own ML model.
It was developing the model and practicing seeing what worked. and the mistakes too!
The practical part was to create your own intelligence and do the tests.
Developing a program that works in practice.
The part of creating a model, the autonomy of artificial intelligence. And during the classes I liked the incentive from the teachers to participate and enter the IT world.
The facility to learn about Machine Learning through the excellent explanations and classes from the professors.
Creating an artificial intelligence to compare images.
The way the course was applied, and also to do it in "practice".
The learning was very good, step-by-step, very intuitive and pleasant.
I liked knowing the importance that Machine Learning has for our future, something I had no idea about.
The ease of understanding the content.
The information brought not only about Machine Learning, but about AI in general. And the attention of the professors. all very attentive and friendly.
I liked learning how to use machine learning tools and learning exactly how one is made
of creating new things and messing with technology.
What I liked most was the practical class, because it is easier to learn.
I liked the teachers' didactics and interaction with the students. (10)
The practical applications (2).
The simplicity with which the information was passed on, making learning easier.
Learning how a neural network works and making an image recognition model.
Doing the Google Teachable Machine activity. (3)
The theory.
The whole course.

The part where we can make our own machine learning model.
The training activity, where I could put my knowledge into practice.
How "dependent" and independent artificial intelligence is.
The perspective of the future passed to the young people.
I didn't know anything about Machine Learning and now I have a notion of how things work.(2)
I liked the classes very much because I found them very well explained
I've been looking at the class slides beforehand even though I can't attend the classes on meet. With these examples I was able to understand the concept and practice of Machine Learning.
Create the model for sure. Being able to make my own neural network
I liked the organization of the classes and the way they were taught.
The mini quizzes in the presentations and the activity of training an AI.
That you don't need to have a background in any previous content to be able to enter and follow the course.' Simple explanation, practical slides and activities for easy learning.
The separation of the categories in the creation of the AI.
Of discovering the google service to create ML Fast.
The part about autonomous cars.
Knowing about the scope of this technology and its applications
Training and testing the Machine Learning model. (2)
It was the presentations made by the professors. (2)
The course was very inclusive to the students. brought related examples. beautiful slides.
It presented an easy way to train an artificial intelligence but with great effectiveness.
I liked the practicality of developing the proposed project and the teachers' orientation.
Having contact with Google Teachable Machine and being able to create an AI with machine learning and a neural network and know a little more about the concept.
When we got hands-on and developed a machine learning model.
Creating a Machine Learning model.
I really liked the teachers' didactics and the quality of the material made available.
It was a lot of fun doing the proposed activities.
What I liked was to create a model that classifies objects with images!.
Learning to create a program that identifies images.
I liked that besides having studied the course, I had the opportunity to put what I learned into practice.' I loved learning a little about artificial intelligence.
The activities.

(#) number of times similar comments were given

Table 8. Weaknesses of the course

What did you like least about the course?
to read,
Hard to understand.
The wait from one class to the next.
Teaching (2)
I don't know (2)
of the site
Difficulty
I liked everything about the course (14)
See the accuracy rate.
I believe that all in all the teaching and understanding was good. which was more proper regarding the difficulty of data collection and final analysis of the percentage of hits.
Filtering the pictures and putting them in a folder to teach the AI.
Choosing and classifying the example images for the program.
Of the possible moral choices in an accident involving AI. such as the program shown in class where the car needs to decide between staying in the right or left lane. both with fatalities.
Nothing to complain about. (14)
The duration, I thought it was pretty fast. (2)
The ease of understanding the content and the need for a huge amount of data.
The time I thought it was bad that I could not identify an activity that was not submitted.
The lack of depth. It was meant to be a short course. but it could be longer and deeper. (4)
The amount of classes. I wish there were more.
I found some things relatively monotonous, which were mentioned before and were repeated several times.
Nothing specific. I just found it a bit boring that my model didn't look very good. but I know what I need to do to improve it.
Think I was expecting something else, but this was even better, so I have no bad points, mainly because it was very fast.' the limitations of my jokes.
The part of class 4.
Separate the images from the dataset.
It could have lasted a little longer, since I found it very interesting.

The delay in some explanations.
Selecting the data and resizing the images.
I had some difficulty in the Teaching Machine environment because it seemed that the screens in the application were different from the slides at some points.
I didn't like the confusion Matrix very much. I found it very confusing.
Few lessons, considering only 8 hours.
Maybe the lack of practical content. I'm more interested in practical content than theoretical. since it animates much more.
Class schedules
There were times when the explanations were long and repetitive.
The short duration of the course, it ends up being superficial. (2)
One of the questionnaires doesn't work
I didn't like having to constantly answer questionnaires.
Although it is essential to organize the database.
It was very easy. maybe it would be interesting to bring more activities.
Not being able to review the lessons.
Unfortunately I was not able to test the AI I created on Google Teachable Machine and thus could not answer the 2nd questionnaire of class 4.
Nothing. I loved doing the course.
I wish it was a little more in depth. possibly working with some kind of introduction to programming.
Not being able to participate in two synchronous activities.
There could be more activities to increase learning.
The day between meetings ended up being tiring.
Practical examples.
It was a little confusing.

(#) number of times similar comments were given

Based on the students' feedback Table 9 presents general considerations about the course.

Table 9. Considerations about the course

Any more comments?
Positive comments
This course has broadened my knowledge and opened new doors of interest. I really enjoyed it and learned a lot.
I really liked the course that was offered. It is interesting to think that a few days ago I had no knowledge about the subject and now the course has added a little more to my knowledge. I thank those who had the initiative and incentive to continue. Thank you
very good
it was good as long as it lasted
I thought the course was very good.
great course!
The slides help a lot in understanding. They are explanatory and easy to read. The exercises are also great for fixing the content. In summary, it is a great course.
the teachers are very friendly and teach well. really concerned if we understand <3 great course
Very good. Excellent quality.
Just that it was very good
thank you teachers
Just thank you for the opportunity to bring us one on machine learning
I'm going to do more machine learning models
The classes were great
I love the teachers! You are making a difference in the lives of many young people. Thank you
Thank you very much for the classes. Unfortunately I missed the last one online but was able to follow along with the help of my father.
I loved the course!
Very interesting course!
I am very grateful for all the learning I got during the course and I am very happy to know about initiatives like this that you bring. Besides, content of excellent quality. accessibility for those who are interested. :D
I liked the way the course went and the information that was presented.
I didn't know this field. I started as a curious person and I liked it a lot!
Constructive comments
I thought the course was very good. However, it could have gone a little deeper into the content that for me was little explored.
I would like to have more classes in the course.
I liked the course a lot, both the didactics and the content, which was presented in a fun and interactive way. It would be nice to have a course presenting Machine Learning using some programming language like python.

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