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Model and Implementation of Optimizing Middle School Curriculum Timetable: A Case Study Based on Xpress

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Abstract: This study explores how to generate a middle school timetable through an optimization model to improve the scientific nature of teaching arrangements and students' learning efficiency. The core of the study is to add new constraints to the basic constraints to ensure that each class is in the fall course from Monday to Friday and optimize the objective function to make the course distribution of the two classes more balanced. We implemented this optimization model using XPress code, studied different schemes, and analyzed their results. Scheme 1 provides a basic timetable, Scheme 2 adds constraints on daily classes, and Scheme 3 further optimizes the time intervals between courses of the same type to ensure review time. The final results show that the optimized timetable can effectively improve students' learning efficiency and reasonably distribute teachers' workload.

Keywords: course scheduling optimization; high school timetabling; constraint programming; XPress optimization; educational efficiency

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1. Introduction

This report outlines the goals, assumptions, and constraints related to the task and details the process of implementing the model using XPress code. Furthermore, the report highlights the approach taken to solve the optimization problem and presents the results, illustrating the impact on both classes. The report has two highlights:

On the basis of completing the basic constraints, a new constraint is added: ensuring that every class has classes from Monday to Friday, making the curriculum more scientific.

Change the objective function to make the courses of the two classes more evenfrom Monday to Friday to improve learning efficiency.

2. Problem Formulation

The number of two-hour lessons each teacher must teach to two classes of students per week x_{ijt} is a binary variable, indicating that class j takes subject i in timeslots t, and its value is

$$xijt = \begin{cases} 1, \text{if class j takes suubject i in timeslots t} \\ 0, \text{else} \end{cases}$$

Among them, Mathematics for Class 1 and Class 2 are taught by Teacher Feckless and Teacher Derivate respectively, so they are treated as two classes in this report. Similarly, Sport in Class 1 and Class 2 are taught by Mr. Muscle and Mrs. Biceps respectively. They are regarded as two classes in this report.

After the above processing, nine subjects were obtained, namely English, Biology, History/Geography, Mathematics (only taught by Mr. Feckless to class1 four times a week), Mathematics (only taught by Mrs. Derivate to class2 every week) Four classes), Physics, Philosophy, sport(only taught by Mr. Muscle to class1 on Thursday afternoon between 14:00 and 16:00), sport(only taught by Mrs. Biceps to class2 on Thursday afternoon between 14:00 and 16:00)

Because Classes run from Monday to Friday, and each day has the following slots for courses: 8:00-10:00, 10:00-12:00, 14:00-16:00 and 16:00-18:00. Divide it into 20 time periods, Monday 8:00-10:00, 10:00-12:00, 14:00-16:00 and 16:00-18:00, Tuesday

8:00-10 :00, 10:00-12:00, 14:00-16:00 and 16:00-18:00, and so on.

a) $\sum_{t=1}^{20} x_{ijt} = 1 \qquad i = 1, j = 1$
b) $\sum_{t=1}^{20} x_{ijt} = 1 \qquad i = 1, j = 2$
c) $\sum_{t=1}^{20} x_{ijt} = 3 \qquad i = 2, j = 1$
d) $\sum_{t=1}^{20} x_{ijt} = 3 \qquad i = 2, j = 2$
e) $\sum_{t=1}^{20} x_{ijt} = 2 \qquad i = 3, j = 1$
f) $\sum_{t=1}^{20} x_{ijt} = 2 \qquad i = 3, j = 2$
g) $\sum_{t=1}^{20} x_{ijt} = 0 \qquad i = 4, j = 1$
h) $\sum_{t=1}^{20} x_{ijt} = 4 \qquad i = 4, j = 2$
i) $\sum_{t=1}^{20} x_{ijt} = 4 \qquad i = 5, j = 1$
j) $\sum_{t=1}^{20} x_{ijt} = 0 \qquad i = 5, j = 2$
k) $\sum_{t=1}^{20} x_{ijt} = 3 \qquad i = 6, j = 1$
l) $\sum_{t=1}^{20} x_{ijt} = 3 \qquad i = 6, j = 2$
m) $\sum_{t=1}^{20} x_{ijt} = 1 \qquad i = 7, j = 1$
n) $\sum_{t=1}^{20} x_{ijt} = 1 \qquad i = 7, j = 2$
o) $\sum_{t=1}^{20} x_{ijt} = 1 \qquad i = 8, j = 1$
p) $\sum_{t=1}^{20} x_{ijt} = 0 \qquad i = 8, j = 2$
q) $\sum_{t=1}^{20} x_{ijt} = 0 \qquad i = 9, j = 1$
r) $\sum_{t=1}^{20} x_{ijt} = 1 \qquad i = 9, j = 2$

a) The sport lessons have to take place on Thursday afternoon between 14:00 and 16:00.
   a) $x_{ijt} = (a) \qquad i = 8, j = 1, t = 15$
   b) $x_{ijt} = 1 \qquad i = 9, j = 2, t = 15$

The first time slot on Monday morning is reserved for supervised homework.

a) $\sum_{i=1}^{9} \sum_{j=1}^{2} x_{ijt} = 0 \qquad t = 1$

Mr. Feckless is absent every Monday morning because he is ill.

a) $\sum_{t=1}^{2} x_{ijt} = 0 \qquad i = 4, j = 2$

Mrs. Insulin does not work on Wednesdays.

a) $\sum_{t=9}^{12} \sum_{j=1}^{2} x_{ijt} = 0 \qquad i = 2$

To prevent students from getting bored, every class can only have one two-hour lesson per subject on a single day.

a) $\sum_{t=1}^{4} x_{ijt} \leq 1 \qquad \forall i, j$
b) $\sum_{t=5}^{8} x_{ijt} \leq 1 \qquad \forall i, j$
c) $\sum_{t=9}^{12} x_{ijt} \leq 1 \qquad \forall i, j$
d) $\sum_{t=13}^{16} x_{ijt} \leq 1 \qquad \forall i, j$
e) $\sum_{t=17}^{20} x_{ijt} \leq 1 \qquad \forall i, j$

Each teacher can only teach one class in each timeslots.

a) $\sum_{j=1}^{2} x_{ijt} \leq 1 \qquad i = 1,2,3,6,7 \qquad \forall t$

Each class can only take one lesson per timeslots.

a) $\sum_{i=1}^{9} x_{ijt} \leq 1 \qquad \forall j, t$

2.1. Assumptions Made in the Formulation and Objectives to Be Considered

Option 1: The constraints remain unchanged and the objective function is the total number of class hours per week for the two classes.

Option 2: Add a constraint on the basis of the original constraint: students in the two classes have courses they need to take every day, and the objective function is the total number of class hours in the two classes per week.

Option 3: Keep the constraints of Option 2, and change the objective function to minimize the sum of time slots between subjects of the same type in class 1 + the sum of time slots between subjects of the same type in class 2, ensuring that each subject is given review time.

3. Option 1

3.1. Set Basic Parameters, Variables, Constraints, and Objective Functions

As demonstrated in the following Figure 1, I define the basic parameters and variables of the problem.

```
USES "mmxprs"
DECLARATIONS
    classes = 1..2
    timeslots = 1..20
    subjects=1..9
    CLASSone:array(subjects) OF REAL
    CLASStwo:array(subjects) OF REAL
    x:array(subjects,classes,timeslots) OF MPVAR
END-DECLARATIONS
```

Figure 1. basic parameters and variables.

As demonstrated in the following Figure 2, define the objective function.

```
totalhour:=(SUM(i in subjects,k in classes, j in timeslots)x(i,k,j))*2
```

Figure 2. objective function.

As demonstrated in the following Figure 3, the sport lessons have to take place on Thursday afternoon between 14:00 and 16:00.

```
FORALL(i in subjects,k in classes,j in timeslots|i=8 AND k=1 AND j=15) DO
   x(i,k,j)=1
END-DO
FORALL(i in subjects,k in classes,j in timeslots|i=9 AND k=2 AND j=15) DO
   x(i,k,j)=1
END-DO
FORALL(k in classes) DO
   x(1,k,15)+x(2,k,15)+x(3,k,15)+x(4,k,15)+ x(5,k,15)+x(6,k,15)+x(7,k,15)=0
END-DO
```

Figure 3. Enter Caption.

As demonstrated in the following Figure 4, the first time slot on Monday morning is reserved for supervised homework.

```
FORALL(i in subjects,k in classes) DO
   x(i,k,1)=0
END-DO
```

Figure 4. supervised homework.

As demonstrated in the following Figure 5, Mr. Feckless is absent every Monday morning because he is ill.

```
FORALL(i in subjects,k in classes,j in timeslots|i=4 AND k=2 AND j=1) DO
   x(i,k,j)=0
END-DO
FORALL(i in subjects,k in classes,j in timeslots|i=4 AND k=2 AND j=2) DO
   x(i,k,j)=0
END-DO
```

Figure 5. Mr. Feckless is absent.

As demonstrated in the following Figure 6, Mrs. Insulin does not work on Wednesdays.

```
FORALL(k in classes) DO
   x(2,k,9)+x(2,k,10)+x(2,k,11)+x(2,k,12)=0
END-DO
```

Figure 6. Mrs. Insulin does not work.

As demonstrated in the following Figure 7, to prevent students from getting bored, every class can only have one two-hour lesson per subject on a single day.

```
FORALL(s in subjects,k in classes) DO
   x(s,k,1)+x(s,k,2)+x(s,k,3)+x(s,k,4)<=1
   x(s,k,5)+x(s,k,6)+x(s,k,7)+x(s,k,8)<=1
   x(s,k,9)+x(s,k,10)+x(s,k,11)+x(s,k,12)<=1
   x(s,k,13)+x(s,k,14)+x(s,k,15)+x(s,k,16)<=1
   x(s,k,17)+x(s,k,18)+x(s,k,19)+x(s,k,20)<=1
END-DO
```

Figure 7. prevent getting bored.

As demonstrated in the following Figure 8, each teacher can only teach one class in each timeslots.

```
FORALL(t in timeslots) DO
   x(1,1,t)+x(1,2,t)<=1
   x(2,1,t)+x(2,2,t)<=1
   x(3,1,t)+x(3,2,t)<=1
   x(6,1,t)+x(6,2,t)<=1
   x(7,1,t)+x(7,2,t)<=1
END-DO
```

Figure 8. Each teacher teach one class in each timeslots.

As demonstrated in the following Figure 9, each class can only take one lesson per timeslots

```
FORALL(t in timeslots|t=1 OR t=2 OR t=3 OR t=4 OR t=5 OR t=6 OR t=7 OR t=8 OR t=9 OR t=10 OR t=11 OR t=12 OR t=13 OR t=14 OR t=15 OR t=16 OR t=17 OR t=18 OR t=19 OR t=20) DO
   x(1,1,t)+x(2,1,t)+x(3,1,t)+x(4,1,t)+x(5,1,t)+x(6,1,t)+x(7,1,t) <= 1
END-DO

FORALL(t in timeslots|t=1 OR t=2 OR t=3 OR t=4 OR t=5 OR t=6 OR t=7 OR t=8 OR t=9 OR t=10 OR t=11 OR t=12 OR t=13 OR t=14 OR t=15 OR t=16 OR t=17 OR t=18 OR t=19 OR t=20) DO
   x(1,2,t)+x(2,2,t)+x(3,2,t)+x(4,2,t)+x(5,2,t)+x(6,2,t)+x(7,2,t) <= 1
END-DO
```

Figure 9. Each class take one lesson per timeslots.

As demonstrated in the following Figure 10, output the final solution information

```
writeln("TOTAL HOUR OF TWO CLASSES PER WEEK IS ",getobjval)
 writeln("timetable of class one:")
 FORALL(t in timeslots) DO
 writeln(getsol(x(1,1,t)),";", getsol(x(2,1,t)),";",getsol(x(3,1,t)),";", getsol(x(4,1,t)),";", getsol(x(5,1,t)),";", getsol(x(6,1,t)),";",getsol(x(7,1,t)),";",getsol(x(8,1,t)),";",getsol(x(9,1,t)))
 END-DO
 writeln("timetable of class one:")
 FORALL(t in timeslots) DO
 writeln(getsol(x(1,2,t)),";",getsol(x(2,2,t)),";",getsol(x(3,2,t)),";",getsol(x(4,2,t)),";",getsol(x(5,2,t)),";", getsol(x(6,2,t)),";", getsol(x(7,2,t)),";",getsol(x(8,2,t)),";",getsol(x(9,2,t)))
 END-DO
```

Figure 10. Enter Caption.

3.2. Output

As demonstrated in the following Figure 11, each class outputs 20 lines, representing 20 timeslots within a week, and outputs nine columns, representing the nine processed courses (including two repeated mathematics and sport).

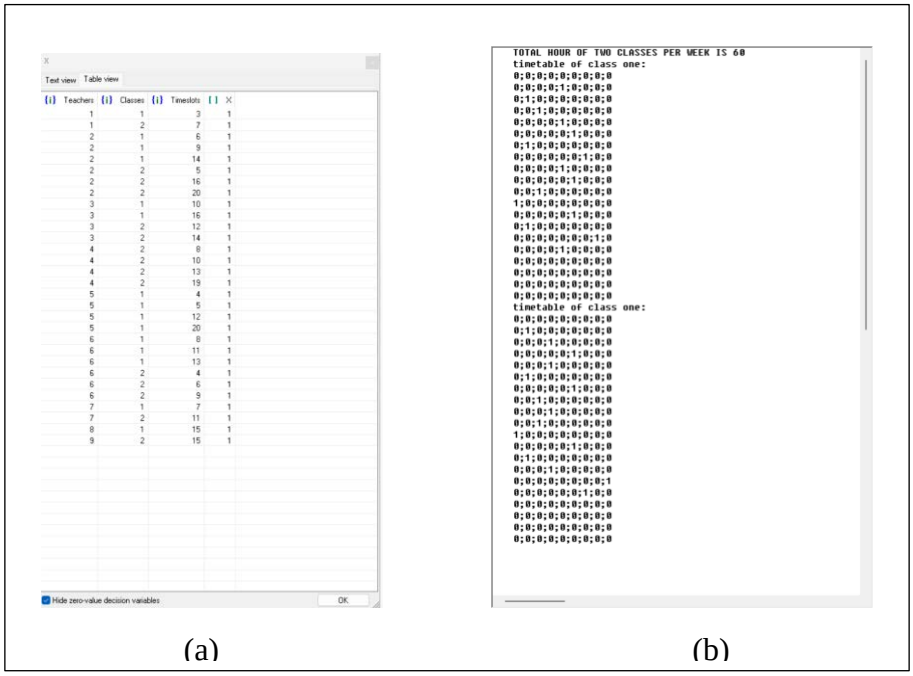


Figure 11. Output.

3.2. Course Schedule Display

The course schedule is shown in Table 1 and Table 2.

Table 1. Course schedule for class 1 in Option 1.

Class1					
time day	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	Friday
8:00-10:00		Mathematics (Mrs. Derivate)	Mathematics (Mrs. Derivate)	Physics (Mrs. Electron)	
10:00-12:00	Mathematics (Mrs. Derivate)	Physics (Mrs. Electron)	Physics (Mrs. Electron)	Biology (Mrs. Insulin)	
14:00-16:00	Biology (Mrs. Insulin)	Biology (Mrs. Insulin)	History/Geography (Mr. Map)	Sport (Mr. Muscle)	
16:00-18:00	History/Geography (Mr. Map)	Philosophy (Mr. Wise)	English (Mr. Cheese)	Mathematics (Mrs. Derivate)	

Table 2. Course schedule for class 2 in Option 1.

Class2					
time day	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	Friday
8:00-10:00		Mathematics (Mr. Feckless)	Mathematics (Mr. Feckless)	Biology (Mrs. Insulin)	
10:00-12:00	Biology (Mrs. Insulin)	Biology (Mrs. Insulin)	History/Geography (Mr. Map)	Mathematics (Mr. Feckless)	
14:00-16:00	Mathematics (Mr. Feckless)	Physics Mrs. Electron)	English (Mr. Cheese)	Sport (Mrs. Biceps)	
16:00-18:00	Physics (Mrs. Electron)	History/Geography (Mr. Map)	Physics (Mrs. Electron)	Philosophy (Mr. Wise)	

4. Option 2

4.1. Add a Constraint

As demonstrated in the following Figure 12, add a constraint on the basis of the original constraint: students in the two classes have courses they need to take every day, and the objective function is the total number of class hours in the two classes per week.

```
FORALL(k in classes) DO
   x(1,k,1) + x(2,k,2) + x(3,k,3) + x(4,k,4)>=1
   x(1,k,5) + x(2,k,6) + x(3,k,7) + x(4,k,8)>=1
   x(1,k,9) + x(2,k,10) + x(3,k,11) + x(4,k,12)>=1
   x(1,k,13) + x(2,k,14) + x(3,k,15) + x(4,k,16)>=1
   x(1,k,17) + x(2,k,18) + x(3,k,19) + x(4,k,20)>=1
END-DO
```

Figure 12. lessons are held every day from Monday to Friday.

4.1. Output

The output result is shown in Figure 13.

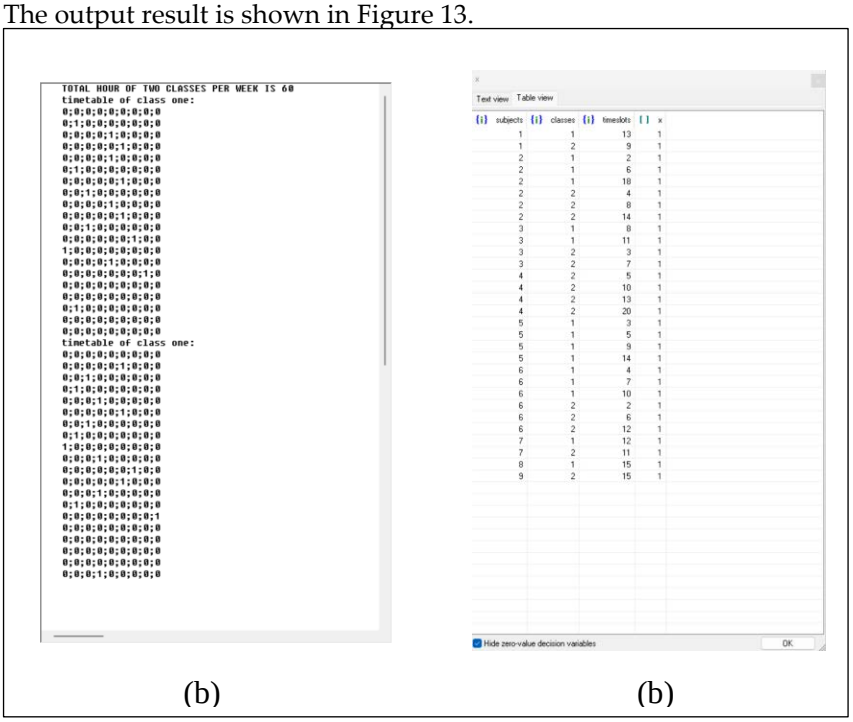


Figure 13. Output.

4.1. Course Schedule Display

The course schedule is shown in Table 3 and Table 4.

Table 3. Course schedule for class 1 in Option 2.

	Class1				
time day	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	Friday
8:00-10:00		Mathematics (Mrs. Derivate)	Mathematics (Mrs. Derivate)	English (Mr. Cheese)	
10:00-12:00	Biology (Mrs. Insulin)	Biology (Mrs. Insulin)	Physics (Mrs. Electron)	Mathematics (Mrs. Derivate)	Biology (Mrs. Insulin)
14:00-16:00	Mathematics (Mrs. Derivate)	Physics (Mrs. Electron)	History/Geography (Mr.Map)	Sport (Mr. Muscle)	
16:00-18:00	Physics (Mrs. Electron)	History/Geography (Mr.Map)	Philosophy (Mr. Wise)		

Table 4. Course schedule for class 2 in Option 2.

Class2					
time day	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	Friday
8:00-10:00		Mathematics (Mr. Feckless)	English (Mr. Cheese)	Mathematics (Mr. Feckless)	
10:00-12:00	Physics Mrs. Electron)	Physics Mrs. Electron)	Mathematics (Mr. Feckless)	Biology Mrs. Insulin	
14:00-16:00	History/Geography (Mr. Map)	History/Geography (Mr. Map)	Philosophy (Mr. Wise)	Sport (Mrs. Biceps)	
16:00-18:00	Biology Mrs. Insulin	Biology Mrs. Insulin	Physics (Mrs. Electron)		Mathematics (Mr. Feckless)

5. Option 3

5.1. Add Two Variables

As shown in Figure 14, add two variables.

```
USES "mmxprs"
DECLARATIONS
    classes = 1..2
    timeslots = 1..20
    subjects=1..9
    CLASSone:array(subjects) OF REAL
    CLASStwo:array(subjects) OF REAL
    x:array(subjects,classes,timeslots) OF MPVAR
gap_class1: array(subjects) OF MPVAR
gap_class2: array(subjects) OF MPVAR
END-DECLARATIONS
```

Figure 14. Add two variablesn.

5.2. Change Objective function

As demonstrated in the following Figure 15, Keep the constraints of Option 2, and change the objective function to minimize the sum of time slots between subjects of the same type in class 1 + the sum of time slots between subjects of the same type in class 2, ensuring that each subject is given review time.

```
totalgap:=SUM(s IN subjects) gap_class1(s) + SUM(s IN subjects) gap_class2(s)
```

Figure 15. change objective function.

5.3. Increment Two Counters

As demonstrated in the following Figure 16, Calculate the time interval between two classes (Class 1 and Class 2) in each subject. Specifically, it calculates how each subject is arranged in time slots and calculates time intervals based on the order of time slots and class selection. These two loops calculate the time gap between the two classes for each subject and store the results in the corresponding arrays gap- class1 and gap-class2. These time intervals are usually calculated to optimize course schedules and ensure that each subject is evenly distributed across classes.

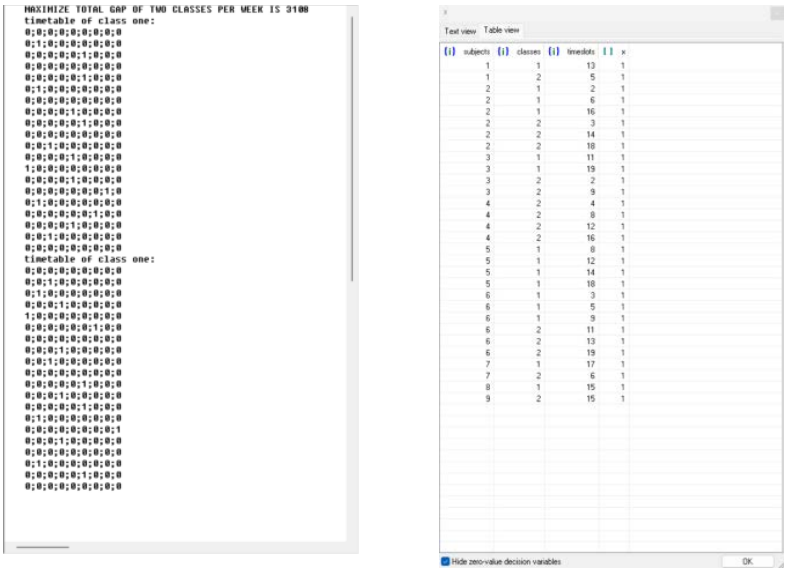
```
FORALL(s IN subjects) DO
   gap_class1(s) = SUM(t IN timeslots | t > 1 AND t < 20) (t - 1) * (1 - x(s, 1, t)) + SUM(t IN timeslots | t > 1 AND t < 20) t * x(s, 1
END-DO

FORALL(s IN subjects) DO
   gap_class2(s) = SUM(t IN timeslots | t > 1 AND t < 20) (t - 1) * (1 - x(s, 2, t)) + SUM(t IN timeslots | t > 1 AND t < 20) t * x(s, 2
END-DO
```

Figure 16. Increment two counters.

5.4. Output

The output result is shown in Figure 17.



(c) (b)

Figure 17. Output.

5.5. The Value of the Objective Function

maximize totalgap =3108

5.6. Course Schedule Display

The course schedule is shown in Table 5 and Table 6.

Table 5. Course schedule for class 1 in Option 3.

Class1					
time day	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	Friday
8:00-10:00		Physics (Mrs. Electron)	Physics (Mrs. Electron)	English (Mr. Cheese)	Philosophy (Mr. Wise)
10:00-12:00	Biology (Mrs. Insulin)	Biology (Mrs. Insulin)		Mathematics (Mrs. Derivate)	Mathematics (Mrs. Derivate)
14:00-16:00	Physics (Mrs. Electron)		History/Geography (Mr.Map)	Sport (Mr. Muscle)	History/Geography (Mr.Map)
16:00-18:00		Mathematics (Mrs. Derivate)	Mathematics (Mrs. Derivate)	Biology (Mrs. Insulin)	

Table 6. Course schedule for class 2 in Option 3.

Class2					
time day	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	Friday
8:00-10:00		English (Mr. Cheese)	History/Geography (Mr. Map)	Physics (Mrs. Electron)	
10:00-12:00	History/Geography (Mr. Map)	Philosophy (Mr. Wise)		Biology (Mrs. Insulin)	Biology (Mrs. Insulin)
14:00-16:00	Biology Mrs. Insulin		Physics (Mrs. Electron)	Sport (Mrs. Biceps)	Physics (Mrs. Electron)
16:00-18:00	Mathematics (Mr. Feckless)	Mathematics (Mr. Feckless)	Mathematics (Mr. Feckless)	Mathematics (Mr. Feckless)	

6. Analysis of the Results of the Three Options

The three course scheduling plans all met the requirements of the homework. Option 2 and 3 were optimized on this basis.

6.1. Result Analysis of Option 1

There are a total of 60 hours of classes per week for both classes. This result provides a class schedule that satisfies all constraints to ensure that each class has appropriate subject placement at each time slot, but there are no classes scheduled for Friday. , this will cause students to slack off in studying on Friday, so the next step is to add constraints to ensure that there are lessons every day from Monday to Friday.

6.2. Result Analysis of Option 2

In this curriculum, daily time slots are allocated to different subjects, ensuring that each class has a schedule throughout the week. This is consistent with the typical school schedule design, in which students attend classes every day.

6.3. Result Analysis of Option 3

This objective function may help reduce the workload of students and teachers and provide more time for rest and independent learning.

7. Conclusion

Because students have different levels of concentration on learning throughout the day, they usually learn most efficiently in the morning. If the weight of each course's importance to students can be given, then on the original basis, courses with greater weight will be prioritized among the four slots every day.

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