**Supporting Information**

**for**

**Traditional vs. UV-Cured Coatings – an Inquiry-Based Experiment Introducing Green Chemistry for High School Students**

**Kinga Orwat1, Paweł Bernard1,\*, Szymon Wróblewski2, James D. Mendez3**

*1Department of Chemical Education, Jagiellonian University in Kraków, 2 Gronostajowa Str. 30-387 Krakow, Poland*

*2PPG Polifarb Cieszyn, 16 Chemików Str. 43-400 Cieszyn, Poland*

*3Indiana University – Purdue University Columbus, 4601 Central Ave., Columbus IN 46131 USA*

\**pawel.bernard@uj.edu.pl*

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# STUDENT HANDOUT

## Preparation of a traditional lacquer

**Reagents:** 2-propanone (acetone), cellulose nitrate or table tennis balls

**Laboratory equipment:** wide-mouth bottle with screw cap (200 ml), magnetic stirrer, stir bar, watch glass, technical balance.

**Safety:** Wear goggles, laboratory coat and gloves! Acetone is a highly flammable liquid and its vapors may cause respiratory irritation. Do not breathe fumes. Synthesis of the lacquers must be carried out in a fume hood!

**Procedure:** Put a 200 ml bottle on a balance and add 45 g of acetone and 5 g of cellulose nitrate (table tennis balls). Next, put into the bottle a stir bar and cover it with a watch glass. Remember to write down mass of the bottle with reactants, stir bar and watch glass! Now place everything on a magnetic stirrer and start mixing. Continue mixing until the nitrocellulose dissolves completely (about 20 minutes). Avoid vigorous mixing in order to prevent foaming and splashing of the lacquer. When the mixture is homogeneous, weigh your bottle once again (with stir bar and watch glass) and add acetone to replace that which evaporated, mix the lacquer for two more minutes.

Your lacquer is ready! Take out the stir bar from the bottle (using a second stir bar as magnet), and close the bottle tightly with a screw cap.

Now you can paint with the lacquer you made. Remember to do it in a fume hood! Close the bottle tightly after painting! Place the painted surface in the laboratory oven for 10 minutes at 50 °C. Wash your paintbrush and other tools with acetone. Put all of the wastes in an appropriate organic waste container. **Remember to fill in the worksheet as you work!**

## Preparation of a UV-cured lacquer

**Reagents:** photoinitiator: Irgacure 500; reactive diluent: Laromer TMPTA; prepolymer: Laromer 9033

**Laboratory equipment:** dark wide-mouth bottle with screw cap (200 ml), ring stand with clamps, mechanical stirrer.

**Safety:** Wear goggles, laboratory coat and gloves! Synthesis of the lacquers must be carried out in a fume hood! Do not breathe fumes.

**Procedure:** Put a 200 ml bottle on a balance and add 25 g of Laromer TMPTA, 22.5 g of Laromer 9033, and 2.5 g of Irgacure 500. If you aim to obtain a white lacquer, add 3 g of TiO2. Put the bottle on the extension clamp under mechanical stirrer. Turn on mixing, and set the rotation low enough to prevent splashing and foaming of the lacquer (speed in the range of 250-350 rpm). Mix it for 20 minutes.

Your lacquer is ready! Keep it in a closed bottle and store in a dark place. Do not expose the container to sunlight!

Now you can paint with the lacquer you made. Remember to do this in a fume hood! Put the painted surface under UV lamp for 2 minutes. Do not stare at UV light, wear googles with UV filter. Do not expose the bottle with lacquer to the sunlight or UV radiation from the lamp. Wash your paintbrush and other tools with acetone. Put all of the wastes in an appropriate organic waste container. **Remember to fill in the worksheet as you work!**

## Tests of coating properties

**The “thumb-twist” test**

This test allows you to check whether the lacquer is cured completely and if it is firmly attached to the surface. The test is very simple, just touch the surface of the lacquer with your thumb, press it down and rotate. The coating can be tacky, deform under pressure and during twisting, or slip on the surface of the material. The degree of the lacquer curing is usually classified in scale 1 to 5, where 1 corresponds to an uncured lacquer, and 5 to a completely cured one.

**The permanganate stain test**

This test will also inform you about the completion of the curing process. Place a small amount (1-3 drops) of 1% KMnO4 solution on the coating. After 1 minute, wipe the drop with a piece of paper and check the surface for brown stains. Formation of brown stains is an effect of a chemical reaction in which brown MnO2 is created. It indicates that the lacquer had not been cured completely. Define the degree of the lacquer curing in a scale from 1 to 5, where 1 corresponds to an uncured lacquer, and 5 to a completely cured lacquer.

**Pencil hardness test**

The hardness of the coating can be determined by comparison with the hardness of graphite in pencils. For this purpose, pencils of various hardness from 8B (very soft) to 5H (very hard) are used. Place the pencil with sharp tip perpendicularly over the tested coating and press the pencil down. Start tests with the softest pencil. If the pencil breaks off and no dent on the coating is visible, the pencil is softer than the lacquer. Repeat the test with pencils with higher hardness until a dent is noticed. The coating hardness can be defined in the pencil hardness scale:

|  |
| --- |
| very soft 8B, 7B, 6B, 5B, 4B, 3B, 2B, B, H, 2H, 4H, 5H very hard |

The test may be carried out only for coating on hard surfaces. Special caution should be taken during a test on glass.

**Adhesion and Elasticity test**

Coatings applied on elastic surfaces, i.e. Leneta cards, can be tested for their adhesion and elasticity. For this purpose, bend the coated material and check whether the lacquer layer has not been breached. Define the degree of adhesion and elasticity of the coating in a scale from 1 to 5, where 1 corresponds to a non-adhesive and poorly elastic coating, and 5 corresponds to an adhesive and elastic one.

**Brittleness test**

The brittleness test is carried out similarly as the adhesion test. In this case, bend flat the coated material. Then, evaluate the straightened material for numbers of lacquer fractures and breaks at the crushing edge. Classify brittleness of the coating in the scale of 1-5 (1 – very elastic, 5 – very brittle).

**Remember to fill the worksheet as you work!**

## Student worksheet

**Group …………..**

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Lacquer** | **Surface** | **m0**  **[g]** | **m1**  **[g]** | **m2**  **[g]** | **m**  **[g]**  **[%]** | **Test** | | | | | |
| **„thumb-twist”** | **permanganate stain** | **pencil hardness** | **adhesion and elasticity** | **brittleness** | **covering** |
| **Scale:** | **Scale:** | **Scale:** | **Scale:** | **Scale:** | **Description** |
|  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |

m0 – mass of the surface to be painted

m1 – mass of wet lacquer applied to the surface

m2 – mass of the lacquer at the painted surface after curing

m – loss of lacquer mass

# NOTES FOR INSTRUCTOR

## Exemplary results of coating tests

Results obtained by students for traditional lacquer based on white table tennis balls, painting method: Wire-Cator 32 µm.

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Lacquer** | **Surface** | **m0**  **[g]** | **m1**  **[g]** | **m2**  **[g]** | **m**  **[g]**  **[%]** | **Test** | | | | | |
| **„thumb-twist”** | **permanganate stain** | **pencil hardness** | **adhesion and elasticity** | **brittleness** | **covering** |
| **Scale:** *1-5,*  *where*  *1 – uncured lacquer,*  *5 – completely cured lacquer.* | **Scale:** *1-5*  *where*  *1 – uncured lacquer,*  *5 – completely cured lacquer.* | **Scale:**  *8B-5H*  *8B – very soft,*  *5H – very hard.* | **Scale:** *1-5*  *where*  *1 non-adhesive and poorly elastic,*  *5 – adhesive and elastic.* | **Scale:** *1-5*  *where*  *1 – very elastic,*  *5 – very brittle.* | **Description** |
| **Traditional lacquer (white)** | **Leneta chart** | 5.28 | 5.33 | 5.30 | 0.03  60% | 4  The lacquer surface is cured and is not sticky but it shells off during twisting. | 5  No brown stain observed. | *The card is too soft for testing.* | 5  Coating adheres well to the surface, it is intact even after bending several times. | 2  Lacquer doesn’t crack, but there are wrinkles on the fold line. | The coating is very thin and barely visible, the dark color of the card is clearly visible. |
| **Glass** | 96.07 | 96.59 | 96.14 | 0.45  0.87% | 5  The lacquer surface is cured and is not sticky. | 5  No brown stain observed. | B  The lacquer crumbles and splashes. | *Glass cannot be bent.* | *Glass cannot be bent.* | The coating is very thin, texture from the applicator is clearly visible. |
| **Wood** | 90.10 | 91.41 | 90.11 | 0.30  97% | 5  The lacquer surface is cured and is not sticky. | 4  Pale brown stain observed. | *The wooden board is too soft for testing.* | *The wooden board cannot be bent.* | *The wooden board cannot be bent.* | The coating is uniform but very thin and barely visible, lacquer soaked into the wood. |
| **Plastic** | 4.90 | 5.23 | 4.98 | 0.25  76% | 5  The lacquer surface is cured and is not sticky. | 4  Pale brown stain observed. | *The piece of plastic too soft for testing.* | 5  Lacquer is flexible and adheres to the surface. | 4  Lacquer doesn’t crack, but there are wrinkles on the fold line after repeated bending. | The coating is very thin and barely visible. |

Exemplary results obtained by students for UV lacquer with TiO2, painting method: Leneta Wire-Cator 32 µm.

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Lacquer** | **Surface** | **m0**  **[g]** | **m1**  **[g]** | **m2**  **[g]** | **m**  **[g]**  **[%]** | **Test** | | | | | |
| **„thumb-twist”** | **permanganate stain** | **pencil hardness** | **adhesion and elasticity** | **brittleness** | **covering** |
| **Scale:** *1-5,*  *where*  *1 – uncured lacquer,*  *5 – completely cured lacquer.* | **Scale:** *1-5*  *where*  *1 – uncured lacquer,*  *5 – completely cured lacquer.* | **Scale:** *8B-5H*  *8B – very soft,*  *5H – very hard.* | **Scale:** *1-5*  *where*  *1 non-adhesive and poorly elastic,*  *5 – adhesive and elastic.* | **Scale:** *1-5*  *where*  *1 – very elastic,*  *5 – very brittle.* | **Description** |
| **UV (white)** | **Leneta chart** | 5.26 | 5.72 | 5.68 | 0.04  8.7% | 4  The lacquer surface is cured, slightly sticky,  there are delicate marks after several presses and twists. | 2  Brown stain visible but not very intense. | *The card is too soft for testing.* | 4  After a single bend the lacquer adheres well to the surface, but after bending several times begins to come off. | 5  Lacquer splits along the bend. | Uniform, well visible white coating. |
| **Glass** | 97.60 | 98.51 | 98.47 | 0.04  7.4% | 5  The lacquer surface is cured and is not sticky. | 2  Brown stain visible but not very intense. | H  The lacquer crumbles and splashes. | *Glass cannot be bent.* | *Glass cannot be bent.* | Well visible white coating, in some areas delicate texture from the applicator is noticeable. |
| **Wood** | 97.00 | 98.17 | 98.13 | 0.04  3.4 % | 5  The lacquer surface is cured and is not sticky. | 1  Intense brown stain. | *The wooden board is too soft for testing.* | *The wooden board cannot be bent.* | *The wooden board cannot be bent.* | Uniform, well visible white coating. |
| **Plastic** | 5.54 | 5.98 | 5.96 | 0.02  4.5% | 5  The lacquer surface is cured and is not sticky. | 1  Intense brown stain. | *The piece of plastic is too soft for testing* | 5  The lacquer is flexible and adheres to the surface. | 3  Lacquer ripple and crack  after several bends. | Uniform pale white coating with slight gloss. |

## Exemplary group workflow

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Groups | **UV-cured lacquer** | | | | | | | | | | | **Traditional lacquer** | | | | | | | | | | | Notes |
| **Colorless** | | | | | **White** | | | | | | **White**  (based on cellulose nitrate) | | | | | **Color**  (based on table tennis balls) | | | | | |
| Painted surface | | | | | | | | | | | Painted surface | | | | | | | | | | |
| **Leneta chart** | **Wood** | **Plastic** | **Glass** | **Cardboard** | | **Leneta chart** | **Wood** | **Plastic** | **Glass** | **Cardboard** | **Leneta chart** | **Wood** | **Plastic** | **Glass** | **Cardboard** | | **Leneta chart** | **Wood** | **Plastic** | **Glass** | **Cardboard** |  |
| Group 1 | x | x | x |  |  | |  |  |  |  |  | x | x | x |  |  | |  |  |  |  |  |  |
| Group 2 |  |  |  |  |  | | x | x |  |  | x |  |  |  |  |  | | x | x |  |  | x |  |
| Group 3 | x |  |  | x | x | |  |  |  |  |  | x |  |  | x | x | |  |  |  |  |  |  |
| Group 4 |  |  |  |  |  | | x |  | x | x |  |  |  |  |  |  | | x |  | x | x |  |  |

## Pre and post-test

1. Describe briefly drying of:
2. UV lacquer

|  |
| --- |
|  |

1. Traditional lacquer

|  |
| --- |
|  |

1. Link the following features with the lacquer type, some of them can fit either type or both of them:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | | 1. Expensive purchase and use |  | |
| 1. May be used for painting of wood |
| 1. Its use is hazardous to the environment |
| 1. May be applied with a paintbrush |
| 1. May have various colors |
| 1. It is a thick liquid |
| 1. May be used for painting of metal |
| UV  LACQUER |  | 1. May be applied by spraying |  | TRADITIONAL LACQUER |
| 1. Is flammable |
|  | | 1. It’s emission to the environment is hazardous to humans and animals |  | |
| 1. May be applied in multiple layers, one onto another |
| 1. Must be stored in a dark container |
| 1. Has unpleasant odor |
| 1. Painted surface is dried in seconds |
| 1. May be used for painting of fingernails |

1. Evaluate on a scale of 1 – 5 (1 – very easy, 2 – easy, 3 – neutral, 4 – difficult, 5 – very difficult) how difficult is preparation in the laboratory:
2. UV lacquer

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 1 2 3 4 5 | | | | | |
|  |  |  |  |
|  |  |  |  |
| very easy | | | very difficult | | |

1. Traditional lacquer

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 1 2 3 4 5 | | | | | |
|  |  |  |  |
|  |  |  |  |
| very easy | | | very difficult | | |

Select the correct answer in below tasks, in each case 1 answer is correct\*:

1. Green chemistry aims to:
   1. Design chemical products and process that maximize profits
   2. Design safer chemical products and processes that reduce or eliminate the use and generation of hazardous substances
   3. Design chemical products and processes that work most efficiently
   4. Utilize non-renewable Energy
2. Which of the following are among the 12 Principles of Green Chemistry:
   1. Design commercially viable products
   2. Use only new solvents
   3. Use catalysts, not stoichiometric reagents
   4. Re-use waste
3. Green chemists reduce risk by:
   1. Reducing the hazard inherent in a chemical product or process
   2. Minimizing the use of all chemicals
   3. Inventing technologies that will clean up toxic sites
   4. Developing recycled products
4. Which of the following is a challenge for green chemists:
   1. Awareness of the benefits of green chemistry
   2. Developing chemicals that are recyclable
   3. Training for cleaning up chemical spills
   4. Knowing when to reduce and eliminate hazardous waste
5. Business benefits of green chemistry include:
   1. Reduced costs associated with waste treatment and disposal
   2. Innovating 'greener' products to entice customers
   3. Greater compliance with environmental legislation
   4. All of the above
6. Green chemistry is more expensive than traditional chemistry:
   1. True
   2. False
7. This word is synonymous with green chemistry and also means harmless, or gentle and not life threatening:
   1. Sustainable
   2. Benign
   3. User friendly
   4. Greenness
8. Which of the following is the greenest solvent:
9. Formaldehyde
10. Benzene
11. Ethanol
12. Water
13. The definition of green chemistry is the same as the definition of sustainability:
    1. True
    2. False
14. Environmental benefits of green chemistry include:
15. Fewer raw materials and natural resources used
16. Cleaner production technologies & reduced emissions
17. Smaller quantities of hazardous waste to be treated and disposed of
18. All of the above
19. Green chemistry can provide green technology solutions for a sustainable future?
    1. True
    2. False
20. An example of green chemistry is:
    1. Recycled carpet
    2. A product made on Earth Day
    3. A sublimation reaction
    4. Bio-plastics
21. Bio-catalysis has become very useful in green chemistry manufacturing:
    1. True
    2. False
22. The term missing in Risk = Hazard x \_\_\_\_\_\_\_\_ is:
23. Exposure
24. Cancer
25. Benign
26. Reactivity

\*Questions 4-17 were developed by ACS Green Chemistry Institute.

Green chemistry high school test questions: <https://www.acs.org/content/dam/acsorg/greenchemistry/education/resources/green-chemistry-test-questions-library.pdf>

## Key for pre and post-test

1. Describe briefly drying of:
2. UV lacquer

|  |
| --- |
| *Photoinitiator absorbs UV light and generates free radicals. Chain reaction starts in which monomers with double bonds undergo polymerization.* |

1. Traditional lacquer

|  |
| --- |
| *Organic solvent evaporates and nonvolatile ingredients stay on the surface creating coating.* |

1. Link the following features with the lacquer type, some of them can fit either type or both of them:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | | 1. Expensive purchase and use |  | |
| 1. May be used for painting of wood |
| 1. Its use is hazardous to the environment |
| 1. May be applied with a paintbrush |
| 1. May have various colors |
| 1. It is a thick liquid |
| 1. May be used for painting of metal |
| UV  LACQUER |  | 1. May be applied by spraying |  | TRADITIONAL LACQUER |
| 1. Is flammable |
|  | | 1. It’s emission to the environment is hazardous to humans and animals |  | |
| 1. May be applied in multiple layers, one onto another |
| 1. Must be stored in a dark container |
| 1. Has unpleasant odor |
| 1. Painted surface is dried in seconds |
| 1. May be used for painting of fingernails |

1. Evaluate on a scale of 1 – 5 (1 – very easy, 2 – easy, 3 – neutral, 4 – difficult, 5 – very difficult) how difficult is preparation in the laboratory:
2. UV lacquer

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 1 2 3 4 5 | | | | | |
|  |  |  |  |
|  |  |  |  |
| very easy | | | very difficult | | |

1. Traditional lacquer

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 1 2 3 4 5 | | | | | |
|  |  |  |  |
|  |  |  |  |
| very easy | | | very difficult | | |

Select the correct answer in below tasks, in each case 1 answer is correct\*:

1. Green chemistry aims to:
   1. Design chemical products and process that maximize profits
   2. Design safer chemical products and processes that reduce or eliminate the use and generation of hazardous substances
   3. Design chemical products and processes that work most efficiently
   4. Utilize non-renewable Energy
2. Which of the following are among the 12 Principles of Green Chemistry:
   1. Design commercially viable products
   2. Use only new solvents
   3. Use catalysts, not stoichiometric reagents
   4. Re-use waste
3. Green chemists reduce risk by:
   1. Reducing the hazard inherent in a chemical product or process
   2. Minimizing the use of all chemicals
   3. Inventing technologies that will clean up toxic sites
   4. Developing recycled products
4. Which of the following is a challenge for green chemists:
   1. Awareness of the benefits of green chemistry
   2. Developing chemicals that are recyclable
   3. Training for cleaning up chemical spills
   4. Knowing when to reduce and eliminate hazardous waste
5. Business benefits of green chemistry include:
   1. Reduced costs associated with waste treatment and disposal
   2. Innovating 'greener' products to entice customers
   3. Greater compliance with environmental legislation
   4. All of the above
6. Green chemistry is more expensive than traditional chemistry:
   1. True
   2. False
7. This word is synonymous with green chemistry and also means harmless, or gentle and not life threatening:
   1. Sustainable
   2. Benign
   3. User friendly
   4. Greenness
8. Which of the following is the greenest solvent:
9. Formaldehyde
10. Benzene
11. Ethanol
12. Water
13. The definition of green chemistry is the same as the definition of sustainability:
    1. True
    2. False
14. Environmental benefits of green chemistry include:
15. Fewer raw materials and natural resources used
16. Cleaner production technologies & reduced emissions
17. Smaller quantities of hazardous waste to be treated and disposed of
18. All of the above
19. Green chemistry can provide green technology solutions for a sustainable future?
    1. True
    2. False
20. An example of green chemistry is:
    1. Recycled carpet
    2. A product made on Earth Day
    3. A sublimation reaction
    4. Bio-plastics
21. Bio-catalysis has become very useful in green chemistry manufacturing:
    1. True
    2. False
22. The term missing in Risk = Hazard x \_\_\_\_\_\_\_\_ is:
23. Exposure
24. Cancer
25. Benign
26. Reactivity

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Green chemistry high school test questions: <https://www.acs.org/content/dam/acsorg/greenchemistry/education/resources/green-chemistry-test-questions-library.pdf>

## Pre and post-test results

**Q1. Describe briefly the drying mechanism of:**

1. UV lacquer
2. Traditional lacquer

In the description of the drying process for both types of lacquers, the following elements were taken into account: whether the student answered the question, if yes, then whether the answer may be considered correct, and the level of detail of correct answer (in a scale ranging from 1-3, where: 1 – a general description of the curing process, 2 – the student named at least one factor characterizing the drying process, and 3 – the student provided a more detailed description of the process).

Answers 1:

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Lacquer | Pre-test | | | | Post-test | | | |
| None [%] | Incorrect [%] | Correct [%] | Details level | None [%] | Incorrect [%] | Correct [%] | Details level |
| Traditional | 27 | 34 | 39 | 1.53 | 0 | 3 | 97 | 2.08 |
| UV | 32 | 20 | 48 | 2.43 | 0 | 3 | 97 | 2.55 |

**Q2. Mark, with the arrows, the following statements for the lacquer type, some of them can fit either type or to any of them:**

Answers 2:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Features of the lacquer | Pre-test  [%] | | Post-test  [%] | |
| UV-cured lacquer | Traditional lacquer | UV-cured lacquer | Traditional lacquer |
| 1. Expensive purchase and use | 86 | 2 | 33 | 37 |
| 1. May be used for painting of wood | 39 | 84 | 70 | 70 |
| 1. Its use is hazardous to the environment | 66 | 64 | 5 | 74 |
| 1. May be applied with a paintbrush | 32 | 89 | 60 | 79 |
| 1. May have various colors | 55 | 84 | 79 | 81 |
| 1. It is a thick liquid | 45 | 64 | 79 | 40 |
| 1. May be used for painting of metal | 52 | 55 | 51 | 51 |
| 1. May be applied by spraying | 52 | 57 | 21 | 74 |
| 1. Is flammable | 50 | 64 | 14 | 74 |
| 1. It’s emission to the environment is hazardous to humans and animals | 59 | 61 | 12 | 77 |
| 1. May be applied in multiple layers, one onto another | 25 | 93 | 63 | 70 |
| 1. Must be stored in a dark container | 77 | 23 | 67 | 19 |
| 1. Has unpleasant odor | 48 | 75 | 58 | 40 |
| 1. Painted surface is dried in seconds | 59 | 39 | 47 | 14 |
| 1. May be used for painting of fingernails | 45 | 68 | 84 | 56 |

**Q3: Evaluate on a scale of 1 – 5 (1 - very easy, 2 - easy, 3 - neutral, 4 - difficult, 5 - very difficult) how difficult is preparation in the laboratory:**

1. UV lacquer

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 1 2 3 4 5 | | | | | |
|  |  |  |  |
|  |  |  |  |
| very easy | | | very difficult | | |

1. Traditional lacquer

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 1 2 3 4 5 | | | | | |
|  |  |  |  |
|  |  |  |  |
| very easy | | | very difficult | | |

Answers 3:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Test | Lacquer | very easy  [%] | easy  [%] | neutral  [%] | difficult  [%] | very difficult  [%] |
| pre-test | UV lacquer | 13 | 6 | 15 | 55 | 11 |
| traditional lacquer | 0 | 44 | 39 | 14 | 3 |
| post-test | UV lacquer | 5 | 37 | 39 | 16 | 0 |
| traditional lacquer | 11 | 68 | 13 | 5 | 3 |

The average result of the pre-test for the UV-cured lacquer amounted to 3.74, and for the traditional lacquer – 2.50.

The average result of the post-test for the UV-cured lacquer attained of 2.63, and for the traditional lacquer – 2.21

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|  |  |  |
| --- | --- | --- |
| **Multiple choice questions 4-17\*** | Score | |
| Pre-test  [%] | Post-test  [%] |
| Q4: Green chemistry aims to: | 84.1 | 92.1 |
| Q5: Which of the following are among the 12 Principles of Green Chemistry: | 6.8 | 18.4 |
| Q6: Green chemists reduce risk by: | 63.6 | 89.5 |
| Q7: Which of the following is a challenge for green chemists: | 25.0 | 73.7 |
| Q8: Business benefits of green chemistry include: | 56.8 | 86.8 |
| Q9: Green chemistry is more expensive than traditional chemistry: | 40.9 | 84.2 |
| Q10: This word is synonymous with green chemistry and also means harmless, or gentle and not life threatening: | 29.5 | 52.6 |
| Q11: Which of the following is the greenest solvent: | 95.5 | 100.0 |
| Q12: The definition of green chemistry is the same as the definition of sustainability: | 65.9 | 76.3 |
| Q13: Environmental benefits of green chemistry include: | 56.8 | 47.4 |
| Q14: Green chemistry can provide green technology solutions for a sustainable future? | 95.5 | 100.0 |
| Q15: An example of green chemistry is: | 77.3 | 81.6 |
| Q16: Bio-catalysis has become very useful in green chemistry manufacturing: | 77.3 | 94.7 |
| Q17: The term missing in  Risk = Hazard x \_\_\_\_\_\_\_\_ is: | 70.5 | 86.8 |
| Average | 60.4 | 77.4 |

The average result obtained by the students in the multiple choice questions part pertaining to green chemistry amounted to 60.4% before the classes (standard deviation of 2.1), while in the post-test, the students achieved an average result of 77.4% (standard deviation of 2.3). Statistical significance of the difference was confirmed by an analysis of variance with repeated measurements; the level of probability p = 0.00002 was obtained with the assumed significance level α = 0.05 and the assumption of sphericity of the variance fulfilled (calculated in Statistica 12 software).