3D – PRINTED ANATOMICAL MODELS FOR TACTILE TEACHING VISUALLY – IMPAIRED STUDENTS

Jan Sylwester Witowski

Jagiellonian University Medical College, Krakow, Poland

ABSTRACT

Development of three-dimensional printing technologies allowed educators to implement printed models in tactile teaching processes. This paper presents the case of 3D-printed models of body structures, including major body organs. Thanks to many possibilities of adjusting models details, they can be used in every stage of education. Realistic materials and high-detailed structures are much more effective in teaching in comparison to current approach, especially for visually impaired (VI) students.

INTRODUCTION

Recent years were the times of rapid growth of three-dimensional printing and thanks to this technique many areas of life begin to improve. Education, as one of those, will find those opportunities very beneficial, since they create new means of modern teaching. One of the major advantages, that is appreciated by educators familiar with 3D printing, is possibility to use different materials, scale, adjust the details of the models. Those capabilities make this technology a great tool for teaching visually impaired (VI) students.

There is a great difference between making VI disciples imagine things and learn by their description and actually being able to touch them. Unfortunately, so far there have been many barriers. Look at the case of human anatomy – if teacher would be able to provide realistic models of human organs, then VI students would have better understanding of surrounding world.

Researches have been trying to develop various models in order to test, whether they will be useful in work with VI people. We already have seen biological models such as enlarged skeleton models of plankton (Teshima et al., 2010) or models that help understand structure and function of proteins (Herman et al., 2006). This paper presents how we could bring the human anatomy closer to VI students.

DEVELOPMENT OF ANATOMICAL MODELS

Currently, there are multiple approaches to the task of models' development. One of them, very popular, is to manually create desirable structure in available computer software, basing on anatomical atlases, digital images and expert knowledge of physicians. These structures are usually being simplified, preserving their general shape. However, it is up to the designer how detailed the models should be. For example, when designing a heart model, we could decide only to present the actual heart shape without major vessels that are connected with this organ or we could choose the model to be very detailed and expose small coronary arteries on heart surface.

Another way to create anatomical models is the combination of medical imaging with computer segmentation and visualization. This approach allows scientists to create high-detailed, realistic models (Reichinger, Neumüller, Rist, Maierhofer, & Purgathofer, 2012) of body structures. It also provides possibility to show variations in the anatomy, pathological changes as well as completely healthy organs. For this development pathway, we use medical digital images, such as: CT (computer tomography), MRI (magnetic resonance imaging), X-ray and some variations of those techniques. Structures are being segmented and visualized with computer software or with algorithmic approach, then they are converted into stereolithography (STL) format that is the final step before the three-dimensional printing itself (Figure 1.).

Taking liver as an example – to fully develop the model of the human liver, the workflow can be started with a regular CT scan. The DICOM format, which is a widespread format of medical images, allows developers to digitally process the image. First, the CT slices can be modified using various filters - including smoothing, edge-preserving, Gaussian or Hessian-based filters (Sato et al., 1997). Then, the processed image can be segmented in order to get single, desired structure. There are many algorithms to complete this task, including level-set, fast marching or watershed methods. Those actions can be executed using open-source programming libraries like ITK – the Insight Toolkit (Ibanez, Schroeder, Ng, & Cates, 2006). Afterwards, file in STL format can be properly set to be prepared for 3D-printing, including its scaling. This can be very useful in designing small models as it allows to print the same structure in different sizes. Realistically sized models can provide information about how structures really look like, whereas enlarged models expose detailed parts. The possibility of printing various sizes gives full experience for VI students of human body structures.

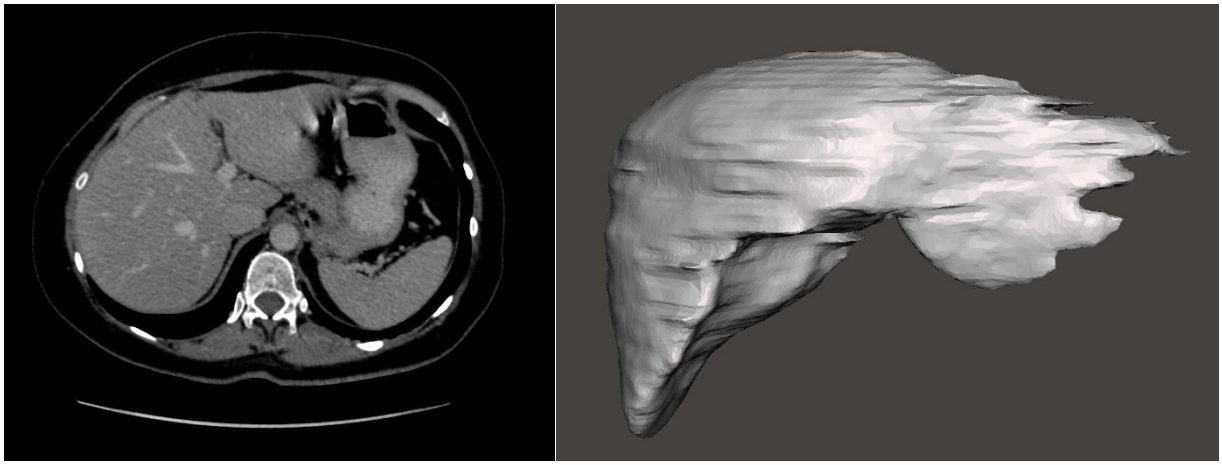

Figure 1. CT scan (left) can be converted into three-dimensional STL models (right) using computer-aided approach. The level of detail can be adjusted and several anatomical structures may be removed to get final, simplified model. Image on the right show liver without any vessels, so that the plastic liver could be used for tactile teaching young VI students about major organs size, location and structure.

Materials are the next parameter of the development process. Today, most popular – thanks to low costs and ease of use – are plastic materials, such as PLA (polylactic acid) or ABS (acrylonitrile butadiene styrene). However, to maintain maximum reality of models, designers may choose to use more complex materials such as metals, gels, resins, and nylon powders.

There is also a rapidly developing field of three-dimensional printing, called bioprinting, which goal is to use human cells to print whole tissues and organs, primarily for medical purposes (Mills, 2015). Biomaterials will definitely create new opportunities for tactile teaching anatomical models, as they will provide feeling sensations of real human tissue. Thus, it may be a great example of teaching for both VI and non-VI students.

PRINTABLE STRUCTURES AND THEIR USAGE IN TACTILE TEACHING

Thanks to high-quality medical imaging techniques, it is possible to print structures that are as small as few millimeters. Available techniques provide tools to make the models extremely detailed. However, there is a question rising – do we need such small models for tactile teaching? The approach can be different for VI students depending on their age and intellectual development.

Anatomy should be taught since the early stages of cognitive development. When teaching VI children, 3D-printed models can be used to present general body structure. Large organs, with a few

details, made out of plastic, are enough to simply explain location and shape. A situation where it can be useful is an example of moment when child complains about pain. He can point to the side or area where the pain is the strongest and where it radiates, and he may even be able to tell – basing on his knowledge – what is located in that body area. However, he won't be able to fully understand what is going on there without knowing how big is the organ and how it is shaped. With that information he can better explain to himself what organ might be the source of pain. Multiple papers have shown that tactile teaching approach gives way better results than previous, non-modern ways of teaching (Witowski, 2014).

Also, when talking about young VI students, qualified educators may use three-dimensional models to explain the body physiology along with the anatomy. That task can be completed by separating body structure into systems: cardiovascular/circulatory, digestive, nervous, muscular, respiratory, urinary, reproductive, skeletal. Notice that there are also endocrine and immune systems, however, they need a different approach, since they range of size is microscopic and they cover a large part of chemical knowledge, not anatomical. Nonetheless, these are topics that may also be simplified, visualized and 3D-printed but yet less realistic.

Base of cardiovascular system, the heart, can be completely designed and printed with all the details. Also, it is possible to print almost every bigger vessel in our body, however when teaching how the system works, it probably isn't necessary. Arteries and veins can be designed in a way to show the differences between their structures so that it is easier to explain how they work. It also is possible to design the whole body model that would include only vessels and bigger organs, so the students can palpably explore location of major arteries and veins and the way they provide blood to different body parts. E.g. portal circulation can be difficult to understand, but when displayed at the three-dimensional model it gets easier to understand for both VI and non-VI students (Fig. 2.).

When teaching older VI disciples, teachers can provide detailed heart models, using various cross-sections to present atria, ventricles, valves or maybe even more complicated structures such as papillary muscles - these printable formations may be used to teach basics of heart physiology.

Digestive system contains large organs that can be printed in real or even reduced size. Intestinal loops, due to their length, may be simplified just to explain their shape and location. Models can be used to compare large and small intestine as well. Plastic models may not give realistic sensation, so more flexible materials, like silicon, should be recommended for this case. Models of liver, pancreas, pancreatic duct, bile duct would be beneficial for teaching physiology of digestion processes at high school and university level (Fig. 2).

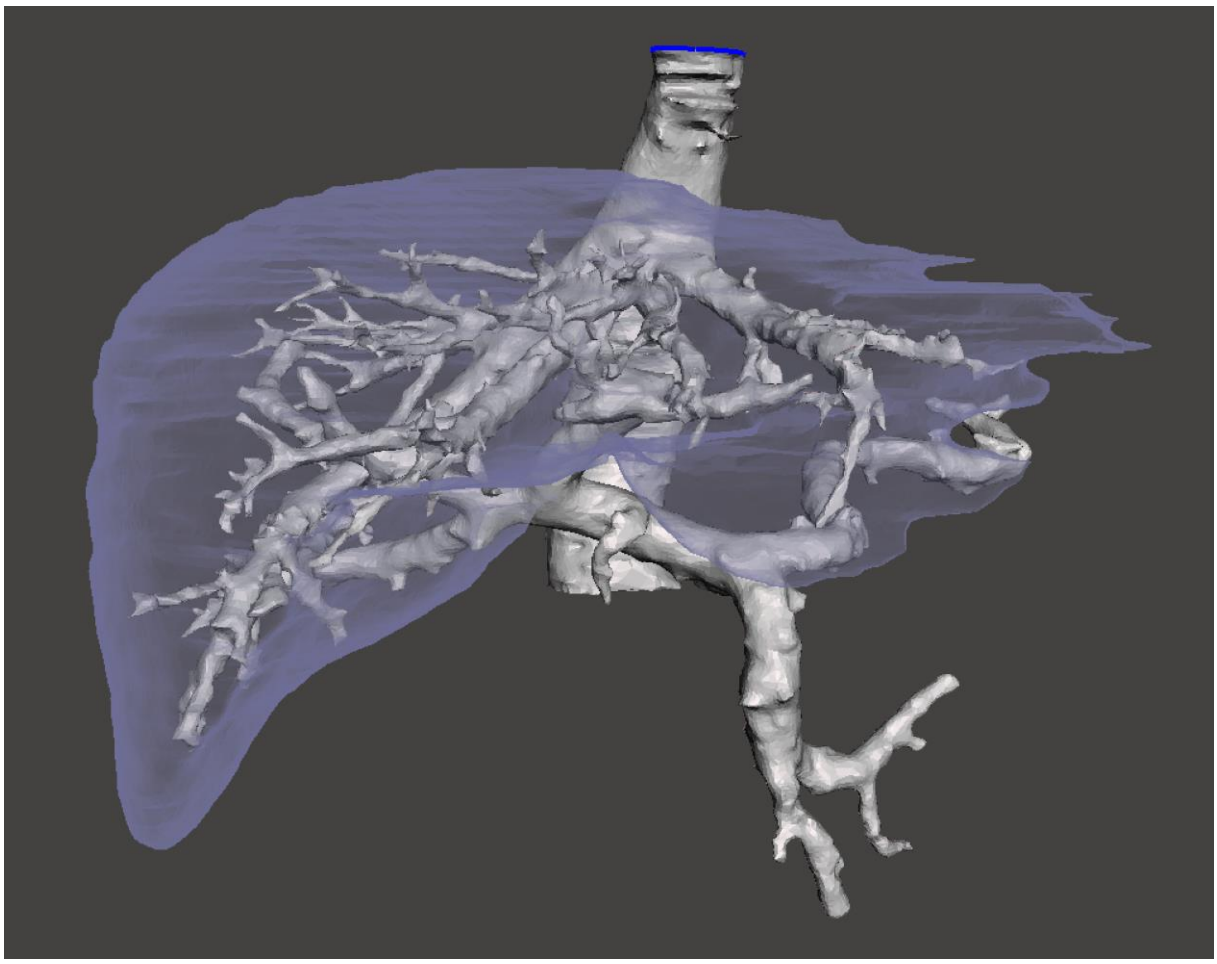

Figure 2. **3D STL (stereolithography) model of liver (blue, semi-transparent) with vascular tree that supplies blood. Printout could be used a primary teaching aid to describe multiple liver functions in terms of i.e. digestive system. This high-detailed model also includes vessels that allow VI students to understand blood flow in portal circulation.**

Nervous system can be explained with the use of 3D-printed models as well. One could use enlarged models of neurons and synapses to explain the physiology of neural conduction. Also, at the

higher stage of education, the brain along with the circle of Willis model could provide some information about that extraordinary type of circulation providing blood to brain.

Recently, there have been released some papers about affordable ways to print three-dimensional models of brain (Naftulin, Kimchi, & Cash, 2015).

Interesting system to model and print is the muscular system, since it is possible to divide some muscle groups, print the muscles one by one and layer them on top of each other, for example when presenting the abdominal wall muscles.

Respiratory system consists of two elements, printing-wise. First is the respiratory tract, which can be easily modeled and printed using simple, affordable materials such as PLA or ABS, since they are close to reality and make the airflow path understandable for students. Second part, the lungs, are more difficult task, since it's important to imitate delicate lung structure, so more elastic materials like resins, gels are recommended.

Urinary and reproductive system is easy to segmentate, thus structures like kidneys (along with their cross-sections), ureters, and urinary bladder would be printed with ease. They can give a little insight about how the blood is filtrated and extra models could be used to explain physiological urine formation process.

The easiest system to model is skeletal system, since the bones structure is simple and they are very easy to segmentate using any of the medical images, whether it is CT or MRI. However, there are already available full-sized human skeleton models. Nonetheless, three-dimensional printing can provide new options – printing single bones in different sizes, using cross-sections to explain inner bone structure. There is also undeniable economic advantage, since skeleton models printed on consumer 3D printers can be more affordable for schools. When it comes to the material used for bones printing, one of the best available for this task would be various powders (Butscher, Bohner, Hofmann, Gauckler, & Müller, 2011), as they would give closest to reality sensation for VI students.

EXTENDED UTILITY OF ANATOMICAL KNOWLEDGE FOR VI STUDENTS

The main goal of described models would be to allow visually impaired students get knowledge about location and shape of organs inside their body. Moreover, physiological processes are going to be significantly easier to understand once they know all the paths, for example blood circulation, urine formation, respiratory tract, gastrointestinal tract.

On top of that knowledge, there are some extra benefits coming from the usage of three-dimensional models. After acquiring such knowledge, young VI people will be able to more precisely describe their health condition. Their quality of life, knowledge about their own health and their own body will increase, with a high degree of certainty.

For person who is visually impaired, including students, it is difficult to understand their condition when they face internal injuries, traumas or other serious medical condition that affect the organs inside their bodies. Being able to know how the organ that suffered feels like raises their awareness, which may lead to easier cooperation and compliance with physician (Naftulin et al., 2015).

ACCESSIBILITY OF 3D-PRINTED MODELS FOR SCHOOLS AND TEACHERS

Currently only a few countries have examples of schools that are using three-dimensional printing as the educational tool. This technology is still gaining popularity and the next few years hopefully will introduce these printers into everyday life, including education, since it can be very affordable and cost-effective when it comes to spending money on teaching aids (Bull, Standish, Johnson, & Haj-Hariri, 2016). And even though some of the educational institutions begin to introduce 3D printers, none of them yet use their power to help VI students, so there is a niche revealing in the educational community.

There are two ways of obtaining teaching materials like 3D models. One is to buy them from companies that mass-produce those objects, second is to make them specifically for the purposes of teachers, inside the school. It is possible with the growth of consumer-focused three-dimensional printers, some of which can be hand-made (Fig. 3.). Ready to print model files are publicly available under open-source licenses in the Internet, decreasing the costs. Some of the materials, such as PLA or STL should be affordable even for smaller schools, and with the upcoming material development growth we should see even more complex structures available to print for consumer users of 3D printers (Bull, Haj-Hariri, Atkins, & Moran, 2015).

The usage of three-dimensional printing technique has even more benefits. Apart from printing models for VI students that could be used in everyday teacher's work with them, non-VI students can work during their school on creating 3D models, working with computer software that is made for this task.

This could lead to an extraordinary cooperation – students who are not burdened with condition impairing their vision can work on special objects for their VI friends and learn together with them, since presented anatomical models can be a tactile teaching tool for both student groups.

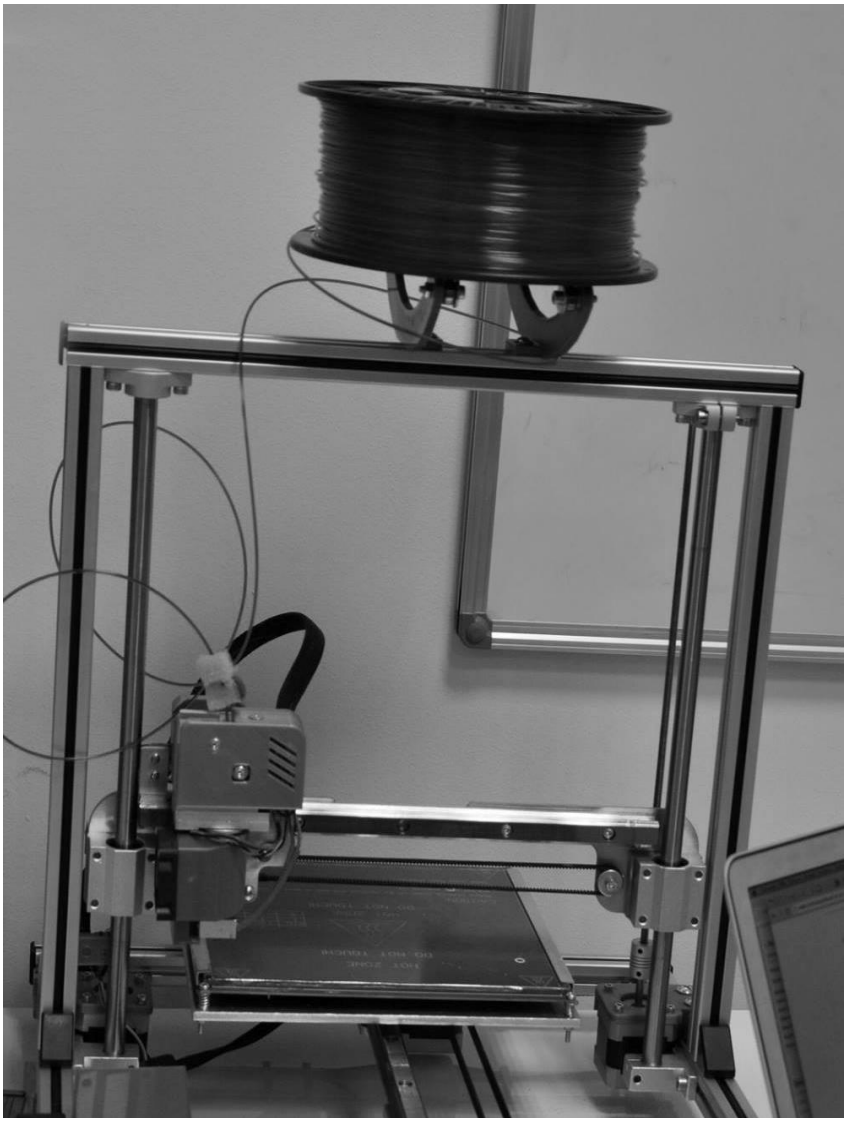

Figure 3. **Hand-made three-dimensional printer, which is able to use PLA and STL as a printing material. Its small size allows educators to quickly print the objects that they specifically need – they are able to make and print the model for VI students to better explain some topics, without need to buy extra educational supplies.**

It is important for school headmasters and heads of research institutions to consider, whether having their own 3D printer wouldn't be more cost-effective. Time needed to print varies from tens of minutes to several hours. Those rapid prototyping devices are safe and relatively easy to use. Also, students find technologies like three-dimensional printing very modern and "fun". That element

might be considered as a prestigious factor for schools, especially these that work with VI students everyday.

Anatomical 3D models could also be used for medical students, and a few medical schools have already tried to start working with those technologies when it comes to teaching anatomy, pathology and physiology (Mahmoud & Bennett, 2015).

SUMMARY

With the rapid development and growth of three-dimensional printing technology there are many opportunities showing up for educators all over the world. There is realistic possibility of using 3D printers to create models for personal use at school, including anatomical models for VI students. Knowledge about human body leads to many benefits apart from acquiring more information.

Educational supplies for students with disabilities were difficult to get so far, mostly because of their costs. Now, with the new approach coming up, it is very likely to see educators who are using state-of-the-art technologies in their everyday job (Bull et al., 2016).

However, several research have to be performed, measuring the effectiveness of tactile teaching anatomy with the usage of 3D models and the cost-effectiveness, with comparison to the current approach. Also, educators have to check empirically through their contact with VI students, what kind of objects, materials and presentations of objects work best. New syllabuses, which take into consideration possibility to use 3D printing, have to be worked out.

All in all, there is no doubt that in the next few years we will see how helpful three-dimensional printing can be for visually impaired students. Hopefully, one of those examples will be the use of anatomical models, from the early stages of education.

REFERENCES

1. Bull, G., Haj-Hariri, H., Atkins, R., & Moran, P. (2015, June 19). An Educational Framework for Digital Manufacturing in Schools. *3D Printing and Additive Manufacturing , 2* (2), pp. 42-49. doi:10.1089/3dp.2015.0009
2. Bull, G., Standish, N., Johnson, E., & Haj-Hariri, H. (2016). Educational Leadership and Planning for Digital Manufacturing in Schools. In *ICT in Education in Global Context - Comparative Reports of Innovations in K-12 Education* (Vol. IV, pp. 173-194). doi: 10.1007/978-3-662-47956-8_9
3. Butscher, A., Bohner, M., Hofmann, S., Gauckler, L., & Müller, R. (2011, March). Structural and material approaches to bone tissue engineering in powder-based three-dimensional printing. *Acta Biomaterialia, 7* (3), pp. 907-920. doi:10.1016/j.actbio.2010.09.039
4. Herman, T., Morris, J., Colton, S., Batiza, A., Patrick, M., Franzen, M., et al. (2006, July). Tactile teaching: Exploring protein structure/function using physical models. *Biochemistry and Molecular Biology Education, 34* (4), pp. 247-254. doi:10.1002/bmb.2006.494034042649
5. Ibanez, L., Schroeder, W., Ng, L., & Cates, J. (2006). *The ITK Software Guide.*
6. Mahmoud, A., & Bennett, M. (2015, Aug). Introducing 3-Dimensional Printing of a Human Anatomic Pathology Specimen: Potential Benefits for Undergraduate and Postgraduate Education and Anatomic Pathology Practice. *Archives of Pathology & Laboratory Medicine , 139* (8), pp. 1048-1051. doi:10.5858/arpa.2014-0408-OA
7. Mills, D. (2015, June). Future Medicine: The Impact of 3D Printing. *J Nanomater Mol Nanotechnol*. doi:10.4172/2324-8777.1000163
8. Naftulin, J., Kimchi, E., & Cash, S. (2015, August 21). Streamlined, Inexpensive 3D Printing of the Brain and Skull. *PLoS ONE , 10* (8). doi:10.1371/journal.pone.0136198
9. Reichinger, A., Neumüller, M., Rist, F., Maierhofer, S., & Purgathofer, W. (2012). Computer-Aided Design of Tactile Models. *Computers Helping People with Special Needs* (pp. 497-504). 13th International Conference, ICCHP 2012, Linz, Austria, July 11-13, 2012, Proceedings, Part II. doi:10.1007/978-3-642-31534-3_73
10. Sato, Y., Nakajima, S., Atsumi, H., Koller, T., Gerig, G., Yoshida, S., et al. (1997). 3D multi-scale line filter for segmentation and visualization of curvilinear structures in medical images. In *First Joint Conference Computer Vision, Virtual Reality and Robotics in Medicine and Medical Robotics and Computer-Assisted Surgery Grenoble, France, March 19–22, 1997 Proceedings* (pp. 213-222). Springer Berlin Heidelberg. doi:10.1007/BFb0029240

11. Teshima, Y., Matsuoka, A., Fujiyoshi, M., Ikegami, Y., Kaneko, T., Oouchi, S., et al. (2010). Enlarged Skeleton Models of Plankton. In K. Miesenberger, J. Klaus, W. Zagler, & A. Karshmer (Ed.), *Computers Helping People with Special Needs. II.* Vienna: 12th International Conference, ICCHP 2010.
12. Witowski, D. (2014, May). Problem of empirical dismutation in teaching natural sciences. *The European Scientific Journal (ESJ) Special Edition*, pp. 211-216. ISSN:1857-7881