On the use of the project interface method when organizing instrumental observations irregular natural phenomena

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Abstract. The work is devoted to the problem of organizing university infrastructure, which allows students to be involved in projects related to instrumental observations of irregular natural phenomena. The purpose of the work is to study factors that simplify the process of organizing and conducting regular measuring experiments, allowing students and teachers of higher Education institutions to study and research rare natural phenomena. At the beginning of the work, an overview of literature is given, which describes the experience of using the project approach as part of the educational process and additional education. The main part of the paper describes an example of creating an educational measuring polygon the GASU. The method of design interfaces is proposed as a technology that allows you to simplify the process of creating a polygon and maintaining it in working order. The final part of the work is devoted to a detailed analysis of an example of a scientific study of an irregular natural phenomenon, the data on which were recorded as a result of the measurement experiments. The discussion section of the work concludes that the project approach and the method of project interfaces make the process of introducing instrumental observations into the educational process effective and beneficial for students.

Introduction

Throughout the world, for many years, the project approach has been used in the system of engineering education as a structural basis (framework) of the educational process. Studying modern educational technologies, one can notice a wide variety of interpretations and implementations of the project approach [1]. For example, leading engineering schools and technical universities in the United States, Canada, Europe, Asia, and New Zealand use an educational technology similar to the project approach which is called «action learning» or practice-oriented learning. The concept of «learning by action» was first used by the English researcher R. Revans in the late 60s of the last century. Along with the term «action learning» in the context of project training, in many publications you can find the expression «learning by doing» [2]. In the German higher education system, the project method is defined as the development of students' cognitive skills, their ability to independently construct their own knowledge, as well as to navigate the information space well. In the Western education system, the term project-led education (PLE) is also often used. It is aimed at the formation of teamwork skills, the skills of studying and solving large-scale and complex tasks in the face of the need to search for reliable information [3]. In addition to teaching students the skills of teamwork, the basis of PLE is used along with training work on fairly serious open projects. In current international engineering education articles by Dym C.L. in [4], Alves A. in [5], Lima R.M. in [6], McCrum D. P. in [7], denoting the project approach, the authors
use the term PBL (project-based learning). A number of works on «problem-based learning» mention an approach based on «Design-Based Learning (DBL)» [8-9]. DBL aims to awaken the creative abilities of schoolchildren and students and their incentive to develop cognitive activity by participating in the development of certain products. In different sources you can find examples in which as educational projects there can be either separate technical solutions or entire complex infrastructure projects. In the work [10], for example, the problem of creating and the necessity of the existence of various geo-sites in the Moscow region is considered: educational, scientific, industrial, demonstration, testing, measuring, and observation. It is noted in the work that such training grounds are simply necessary for carrying out different practices on the subject: geodesic, topographic, geophysical, geographical, geological, geomorphological, geobotanical, hydrological, meteorological, landscape, astronomical, forest taxation, smart farming, etc. The paper [11] also explores the idea of linking an effective educational process in the field of physical geography and a project to create a kind of meteorological polygon in the form of a network of simple meteorological stations. An interesting idea of applying a project approach to the study of meteorological and atmospheric phenomena is discussed in [12].

The project, whose multidisciplinary team, assembled from four universities, was attended by atmospheric experts, meteorologists, engineers, chemists, computer scientists, is dedicated to expanding the capabilities of atmospheric research by integrating unmanned aerial vehicles (UAVs) in the process of measuring experiments. The work [13] also deals with a training project devoted to the measurement of the state (harmful impurities, gases, aerosols) of the surface atmospheric layer. An interesting fact is that the authors used self-made measuring devices based on the Raspberry Pi mini-computer as measuring equipment, and IoT (Internet of Things) technologies were used to transfer, store and monitor data. A similar approach to the development of the equipment used in conducting measurement experiments can be traced in the works [14-15].

Thus, it can be said that the project approach finds application not only when performing engineering developments or when creating complex software systems, but also when conducting interdisciplinary scientific research on the problems associated with the state of the environment, atmosphere, electric and magnetic fields of the Earth. At the same time, the technologies for implementing the project approach itself can be very different. For example, the method of project interfaces proposed in [16] makes it possible to simplify the implementation of a complex project by splitting it into simple, functionally complete «stand-alone» projects (project modules) that interact with each other through a predefined format for exchanging information (interface). At the same time, work on project modules is carried out by specially selected members of the project team.

The purpose of this work is to study the experience of implementing one of the projects related to the study of the environment, currently implemented by employees of the Physics and Mathematics and Engineering and Technology Institute of Gorno-Altaisk state University using the method of project interfaces.

Results
The idea of creating an interdisciplinary measuring polygon appeared as a qualification work in the courses on the use of the project approach in educational activities held for teachers and teachers within the framework of the engineering school «Lift to the future» (Gorno-Altaisk, 2016). As an initial technical task, the idea of organizing infrastructure was worked out, which could be used to simplify the processes of preparing and conducting various measurement experiments related to Earth sciences as much as possible. It was about ensuring uninterrupted power supply in the field, using data transmission and storage systems provided to researchers, organizing round-the-clock video monitoring and temperature-stabilized measuring points, as well as boxes and greenhouses with specified microclimatic parameters necessary for conducting agrotechnological experiments.

In the process of development, for a number of reasons, the initial concept of the measuring polygon has undergone a number of changes. In the final version, the functional task of the polygon was
formulated as follows: providing the minimum infrastructure necessary for continuous measurements (centralized power supply, equipped measuring points); installing simple (possibly DIY) measuring equipment that allows monitoring variations of a number of meteorological indicators and a certain set of parameters of the surface atmospheric layer at a qualitative level; ensuring the transmission and storage of measurement results; preliminary processing and filtering of data obtained as a result of a measurement experiment; development of physical models (maximum plausible explanations) of observed phenomena.

In the course of implementation, the project «Measuring polygon» was divided into independent mutually complementary projects (project modules), which were finalized and put into operation gradually over three years. So the following design modules were highlighted: «Measurements and Monitoring», «Data Pre-Processing and Archiving», «Visualization and Event Search» and «Research and Modeling». Schematically, Structure of interaction of project modules is presented in figure 1.

Each of these project modules can be used by either one person or a project team consisting of a different number of students, undergraduates, postgraduates, and teachers. Project teams can be formed either on a permanent basis or for a specific project.

We would like to dwell in more detail on the project module «Measurements and Monitoring», on which ultimately the quality of the entire measurement process depends. Usually, when implementing instrumental observations, we try to use proven high-quality and very expensive equipment that allows us to conduct observations at a professional level. This approach is explained, on the one hand, by the desire to get as accurate results as possible, and partly by the fact that any data obtained using «non-certified» measurements are simply not considered by reviewers of «serious» journals. Since in our case, due to severe financial constraints, almost all of the equipment used was developed independently within the framework of individual educational and research projects, we could not speak about accurate absolute measurements of physical quantities. Therefore, the idea came up to focus on tracking changes (variations) in the physical parameters of the environment, so that students, participants in measuring experiments, can simply observe at a qualitative level the relationship, for example, changes in the local electric field both during an approaching thunderstorm and during strong dust storms and snowfall. So that young researchers have the opportunity to study not only the figures from reports on the magnitude of earthquakes occurring in the region, but also to observe in practice the dynamics of vibrations of the Earth's surface caused by transverse seismic waves. So that novice analysts can learn, using the apparatus of correlation analysis, to distinguish technogenic infrasound signals from low-frequency noise disturbances caused by gusts of wind. As already mentioned above, equipment that, to one degree or another, met the set objectives, was manufactured and introduced into the measurement process for three years. Below we summarize the characteristics of the sensors and devices used in our measuring polygon:

numerous temperature sensors, both based on DS18b20, and integrated in humidity and pressure sensors installed above the ground, on the ground, placed underground, in thermal boxes placed
in the sun and in the shade of which were tasked with monitoring the dynamics of temperature changes at one local site under various environmental conditions;
compact electronic humidity, pressure and light sensors;
wind speed and direction indicator;
several stationary wire fluxmeters-indicators of atmospheric electric field variations located in several places of the measuring range and oriented in different ways;
experimental design of a thermostabilized «indicator» of longitudinal seismic waves equipped with a magnetic damper with a mechanical suspension system having a natural frequency of 1–2 Hz;
thermostabilized induction «indicator» of the Earth’s magnetic field variations;
several infrasound sensors developed on the basis of specially selected electret microphones, the signal from which was amplified by an original module containing a high-impedance repeater on an operational amplifier, a signal amplifier and an active low-pass filter with a cutoff frequency of about five hertz; in addition, the sensors were installed in spatially separated measuring points of the polygon in combination with ultra-low-frequency resonators of various designs.

Measurements using the sensors listed above were carried out under control of Atmega328 microcontrollers (Arduino Nano platform). All data was digitized using 16-bit analog-to-digital converters. Part of the data, the measurement period of which was about 30–60 seconds, was transmitted using a WiFi connection over the HTTP Protocol via a GET request to a site on the Internet, where it was analyzed by a special program, and placed in a server database. On the same site, a visualization and monitoring system for experimental data was deployed, which made it possible to search for the necessary data for different periods, display information obtained from various measuring points in the form of graphs and save this data, if necessary, in a file. The other part of the data, the measurement period of which was about 80–100 ms, was digitized and recorded by galvanically decoupled serial connection into asynchronous data loggers having external quartz frequency stabilization, equipped with real-time clock and having a special correction function implemented using a GPS receiver with an accurate second signal 1pps sync. Dataloggers were developed on the basis of the PIC24FJ64GA102 microcontroller in various designs and showed fairly good reliability characteristics over a long period of operation. It should be noted that meters and dataloggers are almost autonomous measuring complexes, limited in our case only by the presence of external power and the amount of SD/MMC card used.

We also note that the main «interface interactions» of the measuring design module with the «Data Pre-Processing and Archiving» module concerned data obtained from these modules. It should be noted that an important characteristic of conducted measurement experiments is their regularity. It is the regularity of measurements that allows us to observe daily, seasonal and annual variations in temperature and pressure changes. The regularity in measuring the variations of the surface atmospheric electric field and monitoring the infrasound situation is very important. Further, we would like to give an example of the results of processing the data of regular infrasound monitoring, which made it possible to obtain, although an educational, but rather consistent model of such a rare natural phenomenon as the «visit» of the space «alien», which was developed by the project team involved in modeling. A detailed description of the processing of measurement results is explained by the desire to show the possibility of using this model as a methodological material illustrating the application of many physical laws and formulas in the description of the real observed phenomenon.

We are talking about the collision of a meteoroid with the Earth's atmosphere, which occurred on 08.12.2019 at 18:10:49 local time over South-Western Siberia.

It is known that when space bodies move in the Earth's atmosphere, processes of rapid release of a large amount of energy in a limited volume occur. This leads to the creation of a high-pressure region and the appearance of a shock wave in the atmosphere, which is converted to an N-wave with distance.
In the future, the N-wave becomes acoustic and transforms into an infrasound wave that can spread for hundreds or even thousands of kilometers [17].

A retrospective of the time course of the event under study was modeled on the basis of pre-processed infrasound monitoring data, video recorder readings and an assessment of the geographical location of the points where eyewitnesses were observing an unusual greenish-blue flash, during which it became «as bright as day».

On Sunday, December 8, at approximately 18:10 local time, residents of South-Western Siberia observed a blue-green flash that lit up the sky. Some witnesses also heard a sonic boom that followed the flash. The time was marked according to CCTV cameras and video recorders. Experts who were contacted for comment put forward several versions of the phenomenon.

One of the assumptions was that it was a meteoroid from 0.5 to 1 meter in diameter, according to another, less likely, according to experts, hypothesis, the observed phenomenon could be somehow connected with comet 2I/Borisov, which just had to fly close to the Earth (by cosmic standards at a distance of 150 million km).

The first thing that was noticed when analyzing the observations of eyewitnesses is that the flash was blue-green. The fact is that it is impossible to get a green glow by heating an iron-stone meteorite, since the solid thermal radiation of an incandescent body gives not green, but white light, and with further heating we get blue or purple light (as in electric welding). For example, the maximum radiation from the Sun is green light (555 nm), but we perceive its light as white. The presence of a bright component of green light, therefore, presents a certain problem — which is why some have suggested that the light source was a giant electrical discharge. Apparently, the green light gave a glow to oxygen atoms (a similar occurs during auroras) and it could be excited either by ultraviolet light or by electron impact. However, there were no significant effects of electrical discharges at the time of the outbreak, so the main source of excitation is ultraviolet radiation from a heated body. Similarly, when exposed to ultraviolet light, nitrogen atoms were excited, which produce blue light when emitted.

On the other hand, the fact that the green glow of oxygen atoms did not sink in the stream of light from the heated body itself suggests that there were no lines in the absorption spectrum of the meteoroid material that fall on visible light, because according to Kirchhoff's law for thermal radiation, the ratio of the emissivity of a body at a certain wavelength to its absorption capacity for the same wavelength is a function determined by the emissivity of a completely black body \( r_{bb}(\lambda, T) \):

\[
\frac{r(\lambda, T)}{\alpha(\lambda, T)} = r_{bb}(\lambda, T).
\]

Thus, if the body did not emit visible light with very strong heating, but emitted mainly ultraviolet light, then its absorption spectrum did not contain lines that were visible. Such materials seem white or transparent to us — for example, snow or ice. From all this, it can be assumed that the meteoroid was part of the comet, and not an iron-stone meteorite. The rapid evaporation of ice during heating contributed to its destruction in the upper atmosphere — an iron-stone metroid with such a mass would most likely reach the Earth's surface.

When constructing a model of the phenomenon under study, an attempt was made to estimate the energy of the flash, based on the observations of eyewitnesses. The flash illuminated a huge area—a circle with a diameter of about 300 km: from the Altai territory to the Kemerovo region, the flash was noticed in Ust-Cox, Gorno-Altaiisk, Barnaul, Tashtagol, Biysk, Novokuznetsk, Alesyk, Novoaltaisk. It has already been said above that according to eyewitnesses it became «as light as day» for a second. Note that during the daytime the Sun gives a light intensity on the surface of several hundred W/m². If we assume that the light intensity of the flash was of the order of 1 W/m², then we can estimate the flash power as a tenth of a terawatt:

\[
P = IS = 1 \ W / m^3 \cdot 3.14 \cdot (3 \cdot 10^7 \ m)^2 / 4 \approx 10^{11} W.
\]
Since the flash time was about 1 s, the flash energy can be estimated as a tenth of a Terajoule: 
\[ E = Pt \approx 10^{11} \text{J}. \]

Based on this estimate, it is possible to estimate the mass and size of the meteoroid. At a speed of 30 km/s (the speed of the Earth’s orbit around the Sun), we obtain from the kinetic energy formula 
\[ E = \frac{mv^2}{2} \]
a body mass of about 200 kg.

It should be noted that all the above estimates are quite approximate in nature and can easily change by an order of magnitude up or down. Note also that an encounter with such a small object made of ice is a very rare event, since in The Earth's orbit such small objects evaporate quite quickly by intense solar radiation. With a heat of vaporization of the order of 2,5 MJ/kg, we obtain the energy necessary for the evaporation of the entire material of about 0,8 GJ, therefore, with a light intensity of about 1000 W/m², the life time of such a «snowball» is about 9 days.

Since the above-described event in the collision with the atmosphere left a «trace» not only in the optical, but also in the infrasonic range, the group of researchers also decided to try to estimate the scale of the observed phenomenon, based on the readings of infrasonic sensors.

As mentioned above, the training measuring polygon of the Physics and Mathematics and Engineering and Technology Institute of Gorno-Altaisk state University is constantly monitored by infrasound sensors developed by students and postgraduates of the GASU robotics laboratory, which have a sensitivity of about 0,025 PA at frequencies from 0,1 Hz to 1 Hz and 0,01 PA at frequencies from 1 Hz to 5 Hz. Data from the sensors is recorded in dataloggers that are synchronized using a 1pps signal from GPS receivers and digitize the analog signal with a sampling rate of about 10 Hz. Fig. 2 shows data from one of such infrasound sensors that were processed by a simple normalized difference filter, pre-smoothed by performing a co-evolution (convolution) operation with a Gaussian kernel with a size of 25 samples and a standard deviation of 3.

![Figure 2. Filtered normalized data from the infrasound sensor.](image-url)

To determine the energy of the event that caused the infrasonic vibrations, it is necessary to evaluate the period of oscillations having a maximum amplitude. For the convenience of performing the period estimation procedure, a scaled fragment of the infrasound signal is presented in figure 3.
The estimate of the period according to our data was about 2.35 s. To use an empirical formula,
\[ \log(W/2) = \log(T) \times 4.14 - 3.16, \]
linking the period T of infrasonic vibrations and the energy W in kilotons of the event that caused these oscillations, we can obtain an estimate of the energy and «mass-dimensional» indicators of the observed cosmic phenomenon.

For the obtained estimate of the period of 2.35 s., the energy of the event according to the results of our calculations was 11.89 tons in TNT equivalent. Since 1 ton of TNT is 4.184 GJ, the event energy can be defined as 49.7 GJ. If we assume that the obtained value of the energy of the object fully corresponds to its kinetic energy and the speed of the object upon entering the atmosphere, as was already assumed above, was about 30 km/s (from 11 km/s to 70 km/s for most space objects), then a rough estimate of the mass of the object can be about 110 kg.

If, based on the above reasoning, we assume that the density of the object approximately corresponds to the density of ice ~ 900 kg/m\(^3\), then the volume of such a body could be 0.122 m\(^3\), which corresponds to the diameter of the «ice» ball 0.62 meters.

For further discussion, we would like to pay attention to the beats (local increases and decreases in amplitude) of the infrasound signal, shown in Fig. 2, which have a period of about 20 s. This may mean that the registered vibrations are represented by at least two close frequencies that differ by the beat frequency. Thus, if the main frequency (at \( T = 2.35 \) s) is 0.4255 Hz, then a higher frequency close to it (at a beat frequency of 0.05 Hz) is 0.4755 Hz (\( T = 2.1 \) s). Thus, having performed the energy and mass calculations described above for the period \( T = 2.1 \) s, it is not unreasonable to assume that the shock infrasonic wave was caused by at least two objects into which the space «alien» broke up: one with an energy of 49.7 GJ, and the other with an energy of 31.2 GJ, and having respectively masses of 110 kg and 69 kg and diameters of 0.62 m and 0.53 m. Note that the «infrasonic energy» estimate of the observed phenomenon (80.9 GJ and 179 kg) «not bad» coincides with the «optical energy» estimate (100 GJ and 200 kg).

In the process of studying the model of the observed phenomenon, it was also decided to make an approximate estimate of the place where the space object met the atmosphere. If we take into account the delay between the moment of the blue-green flash (according to the records of the registrars — 18:10:49 local time) and the moment of the beginning of the fixation of the front of the infrasound wave (18:16:46), which is 357 s, then it is possible, although rather roughly try to calculate the distance from the place where the front of the infrasound wave recorded by the sensor «originated» to the measuring polygon of the Physics and Mathematics and Engineering and Technology Institute of Gorno-Altaisk state University. The roughness of the estimate is explained by the unevenness of the sound propagation velocities in the upper and lower layers of the atmosphere.

If we conventionally depict the profile of the distribution of sound speeds depending on the height above the Earth (using knowledge of the temperature distribution and the dependence of the speed of
sound in a gas with a molar mass and adiabatic exponent on temperature T: \( v = \sqrt{\gamma RT/\mu} = 20\sqrt{T} \), then we get the following picture: at altitudes from 150 km to 100 km — 500 m/s; from 100 km to 60 km — 280 m/s; from 60 km to 35 km — 310 m/s; from 35 km to 10 km — 295 m/s; from 10 km — 320 m/s.

To estimate the required distance, we need to know two quantities: the delay before the event is recorded by infrasound sensors (18:10:49–18:16:46), \( t_1 = 357 \) s and the duration of the event fixation time (18:16:46–18:18:14) \( t_2 = 88 \) s. Since the object was moving at supersonic speeds, the infrasound excited during the «entry» of the object into the atmosphere came to us later (with a delay of \( t_1 + t_2 \)) than the infrasound of the end of the event - the moment of the flash and explosion (reached the sensors with a delay of \( t_1 \)). Thus, the graph of the infrasound signal excited by the movement in the atmosphere of a space object must be considered «back to front», i.e. the timeline of the infrasound sensor with increasing time records events from the «end of life» of an object in the atmosphere to its «beginning». Moreover, the lifetime of a space object in the atmosphere is not 88 seconds, as one might assume, based on observations of an infrasound signal, but of the order of 1 second. 88 seconds is the time required to overcome the distance between the point of entry of the object into the atmosphere and the flash point (destruction of the object) with infrasonic waves. If we assume that the outbreak occurred in dense layers of the atmosphere, i.e. at an altitude of less than 100 km, then an estimate of the average speed of sound taking into account the distribution of velocities along the heights could be about 300 m/s, and the distance from the polygon of the Physics and Mathematics and Engineering and Technology Institute of Gorno-Altaisk state University to the flash point is 106 km. If we take into account the experience of space research, which suggests that the destruction of most space objects occurs at altitudes of the order of 80–90 km, then taking an estimate of the altitude of 85 km, we can estimate the distance from the Physics and Mathematics and Engineering and Technology Institute of Gorno-Altaisk state University polygon to the projection of the flash point on the Earth’s surface, which will be equal to 63 km. It is interesting that eyewitnesses from the village of Sovetskoye village in the Altai Territory, which is quite rare for the measuring polygon of the Physics and Mathematics and

As the next step in building the model, we can offer an estimate of the distance from the measuring polygon of Physics and Mathematics and Engineering and Technology Institute of Gorno-Altaisk state University to the point of entry of the object into the atmosphere. For this, it is necessary to determine the path of the passage of infrasound waves from the entry point to the flash point (in 88 s). Since the infrasound propagated at a speed of 280 m/s for a smaller part of the desired path (roughly, let's assume that this is 1/3 of the path), and part of the path at a speed of 500 m/s (heights greater than 100 km), the average speed estimate may be 445 m/s. At such a speed, the infrasound waves will cover a distance of about 39 km in 88 seconds. The height of entry into the atmosphere \( H \) can be estimated from the ratio \( 85/106 = h/39 \), where \( h \) is the difference between the height of the flash and the height of entry into the atmosphere. From this we obtain an approximate estimate of the height difference \( h = 85 \times 39/106 = 31 \) km and the desired height of the entrance of the object into the atmosphere \( H = 85 + h = 116 \) km.

So, summarizing the above calculations, we can say that the space «alien», consisting of ice, which had a mass of 180 to 200 kg, «entered» the atmosphere at an altitude of 116 km (at a distance of 145 km from the infrasound sensor) at a speed of about 30 km/s, it broke up when interacting with the atmosphere into several parts (two of them with masses of 110 kg and 69 kg and diameters of about half a meter), existed for about 1 second, covering a distance of about 39 km, and exploded at an altitude of 85 km (at a distance of 106 km from the infrasound sensor), possibly near the village of Sovetskoye in the Altai territory, radiating at the same time «light» energy from 80 GJ to 100 GJ.

In conclusion, we would like to draw attention to another interesting observation. About half an hour before the flash, a sinusoidal disturbance of the Earth's magnetic field with a period of about 16–20 s was observed, which is quite rare for the measuring polygon of the Physics and Mathematics and
Engineering and Technology Institute of Gorno-Altaisk state University (in conditions of urban noise). (figure 4).

When processing the data, attention was also drawn to the low-frequency “disturbances” of the electromagnetic (electric) field (figure 5), recorded at the same time as the sinusoidal variations of the Earth’s magnetic field. The unusual thing is that similar simultaneous low-frequency variations of the electric and magnetic fields were not previously observed at this measuring range, although, in itself, this may have nothing to do with the flash.

![Graph](image)

**Figure 4.** Slight sinusoidal variations of the magnetic field (according to the readings of the induction sensor of the magnetic field [measuring polygon FMITI GASU]).

![Graph](image)

**Figure 5.** Low-frequency «disturbances» of the electromagnetic (electric) field (according to the indications of a wire fluxmeter [measuring polygon of the Physics and Mathematics and Engineering and Technology Institute of Gorno-Altaisk state University]).

**Conclusion**

In conclusion, we would like to say that the method of project interfaces described in this paper allows us to implement a comprehensive approach to the process of mastering the studied disciplines and organizing scientific research of students, undergraduates and postgraduates. At the same time, the processes of preparing and conducting measurement experiments, preliminary data processing, data search for interesting irregular natural phenomena, description and modeling of these phenomena are included in a single system. This approach, based on a significant interdisciplinary component and the use of data obtained by the organizers of measurement experiments for research, allows to increase the motivation of participants in the educational process both to engage in science and to deeper development of the subjects studied.

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