Competence Improvements with IoT systems

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Abstract. The informatics/programming education in high schools rarely put the new information in context. Thus, the students cannot see the Big Picture, it makes hard to see for them why the new curriculum is important, what kind of problem we would like to solve with it. The main purpose of this research is to identify this issue by asking first semester university students about system related question and to find a solution by using IoT systems in education in or-der to improve their competencies.

Keywords: programming, informatics competencies, real-time systems, embedded systems, raspberry pi, systemic thinking

1.   Introduction

Most often, the *algorithmic thinking* competence comes to front during the high school programming education. In universities as well, it is also true that the focus is rarely on the real-life, complex problems, where multiple technologies, paradigms must be used in an integrated way. The reason why it is an issue, is that the student cannot step out from the concrete tasks from the curriculum, they are not able to see the big picture. For example, we teach the databases in high school [1], but they have no chance to see a live database with a real application, or at least see, why the databases are so important.

In one of our previous articles, we highlighted four from informatics competencies [2], when we tried to find an answer for "with what kind of exercises should we teach the programming" [3]:

- Algorithmic thinking
- Data modelling
- Modelling the real world
- Systemic thinking

At this article, we try to prove, that there are technologies, there is a way to create curriculums to the specific student group (according to their age, interests, goal of the teacher etc.), that includes the improvements of those four competencies (and others of course), so the learners can step out from the *layer of unique elements*, from the usages of the concrete tool to a *systemic layer*, therefor they are able to see the items of the new knowledge in context, they get a different approach.
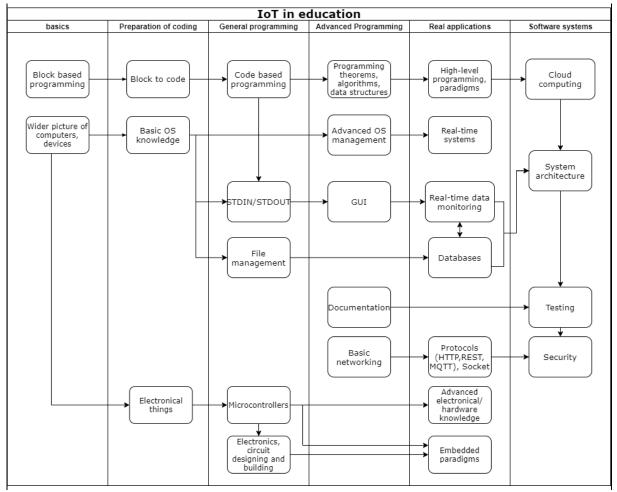
Our examples are the *IoT*[1] *systems*. We try to explain what we would like to/can teach with these tools. At the second part of this article, we prove that the issue is really exist among the students by the results of a questionnaire.

2.   Modules of programming education with IoT systems

In an earlier study [4] based on other articles and university syllabuses [5, 6, 7, 8] a figure was made, where you can find the key modules in a hierarchical order, what shows the elements of a possible

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[1] Internet of Things: Complex system of interrelated devices, which are usually small with one specific purpose. Those devices are constantly communicating with each other (machine-to-machine communication) through a network. The IoT systems are mostly build up with embedded, real-time computers.

IoT curriculum. The original diagram changed a bit since then, we extended and modified it. The updated representation is the first figure.

<p align="center">Figure 1: Modules and the hierarchy between them, that can be taught with IoT systems</p>

However, the figure is applicable not only for IoT system. For example, the GUI, database, testing can easily be the focus in a completely different project from IoT systems. From that point of view the figure is the relationship of small elements and the big picture, and indicates many other questions, because the "the operational components, solving the part problems does not cause the operation of the system" [3]. The main purpose of this article is to prove the hypothesis, that even if the students have already learnt a module, they are not necessarily can interpret that from a higher level or can apply it indirectly, for example if we would ask "in what situations, when we should use a database for what purpose" and not "what the database is". If the proof is successful and the above figure is accepted as a suitable description of programming education with IoT systems, then we have an applicable type of curriculum what is scalable, where the focus point is movable, and what is capable to show the unique elements of a specific problem, and demonstrate its operation in system level at the same time. So, what are the embedded, real-time systems add to programming education? A toolbox to the teacher's hand, that allows them to build a curriculum, that is spectacular, scalable, what is based on the age, background, interests and of course the knowledge of the instructor's wishes and knowledges. Furthermore, with a project in this topic, the students can easily step out from the world of separate elements, so it gives a broader knowledge to them.

2.1. An example

We would like to illustrate the description above with a short syllabus (1ˢᵗ table), which was taught at ELTE with MSc students within *Embedded and Real Time Systems* subject. We moved the focus to *real time systems* just because that was the requirement against the subject. We think that it illustrates well that the IoT systems comes with a great opportunity, includes many technologies and programming paradigms and makes easy to educate the main informatics competencies where the students have no other option but to work and think in systems, they must find solutions that includes many co-operating modules.

The basic assumption was that we would like to build a smart home project based on *Raspberry Pi-s* [2] so that the system is capable of expanding with additional tools (example: a new smart room). We also wanted to monitor the whole system with a graphical application. Of course, important data should be accessible via the internet, and they had to build a local *IoT gateway* as well (which is critical in the industry).

Lesson	Description
1.	**IoT opening:** A quick review about the topic and a demonstration of a real *IoT* project (*real time* data visualization) **Assemble the devices** Go live with the hardware and example codes • How to communicate the *Sense Hat* [3] module (get sensor data, display something in the LED matrix)? • How to control the camera module [4]? • tkinter Python package for GUI applications
2.	**MQTT protocol** Install and configure an MQTT broker and use it for local communication. Use the codes from the previous lesson to get data, and publish it to the broker, subscribe for events and display the incoming information.
3.	**Cloud services** Configure a Firebase real-time database and write create a com-plex Smart Home simulation
4-6.	**IoT lab** – Create independent applications, simulations of a real-time problem (they get the final grade for that project)

Table 1: An *IoT* curriculum in short

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[2] https://www.raspberrypi.org

[3] https://www.raspberrypi.org/products/sense-hat/

[4] https://www.raspberrypi.org/products/camera-module-v2/

We collected the items of the 1ˢᵗ figure, that was involved during these 6*1.5 hours. It can be seen in the 2ⁿᵈ figure, that there were a lot of items (at least at high school level). It can be stated that in a short time the students needed and could create a complex system.
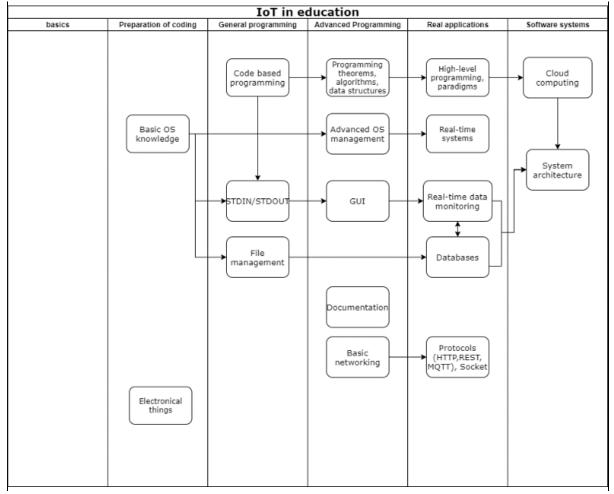

Figure 2: Involved items by the curriculum

The emphasis on scalability is very important. Of course, and exactly same curriculum cannot be presented in a high school, but this is not our goal.

The question is whether this project could be taught to high school students? As we see it, yes. For example, without communicating through the internet by using a *real time* database, or if we would remove the monitoring solution from the system. The building of the MQTT protocol is also not that important.

Is it possible to extend this project with additional items, so that we can show something more to the audience? Yes, there are opportunities, like autonomous testing mechanisms or making a safe *IoT* solution or replace the ready to use *Sense Hat* module with self-made complex circuits etc.

3.   The questionnaire

The questionnaire was filled out by 205 first-year computer science students. The following aspects dominated the formulation of the questions:

- they must be at high school level or maximum what is currently studied
- even if the students give wrong answer to the question, it is still possible that he/she knows the curriculum, will complete the subject successfully
- the questions must about system-level competence, meaning that knowing the answers is essential when applying a particular tool / technology to a larger project, but not necessary when learning the tool

We will explain why these conditions are met for each questions one-by-one. For those that needed a short answer (free text), we had to categorize the result. It was really hard sometimes, because there were so many different answers. You will find those categories on the diagrams, and there will be some examples as well, to make them understandable. On the following section, you can find the questions and the results illustrated by diagrams.

3.1.   Why do we store data in databases and not in files?

The database management is required in high-school graduation. The ability of the students to create tables, modify their contents, write queries in the concrete environment (like Access) does not make sure, that they understand the importance of databases, why they are really useful in real life. Data is stored in files in high-school and in the early years of university as well, so it is not necessarily clear how the databases came into the picture. However, later on it comes inevitable around real application to understand the persistence, transactions and other aspects of data storages.
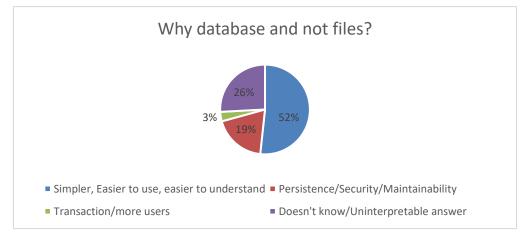

Figure 3: Counted Categorized answers for the first question.

Actually, *persistence and transaction* were never mentioned. Those answers could get here, where we were able to see something that connects somehow to these concepts. The last category contains the answers that we could not interpret like "Compression".

Our opinion is that the result is really sad even if it proves our hypothesis: the students have absolutely no idea why we use databases.

3.2.   What is the difference between a table and a database?

Here, like in the previous question, we wanted to ask about the wider usages of the database. In the intermediate education, students often do not understand why they need to deal with database

management, when spreadsheet tasks are very similar, and many of the database exercises can be solved with table management programs as well. To sum up, it is possible that the students can use the Excel and Access for example, without knowing what the real difference between them is. As a correct answer we would expect that the database is whole management system with several components for example tables, keys, indexes with its own layers like DML, DDL, DAL, a persistence- and data structure logic while a table is just a two dimensional structure with columns and rows. All in all, we do not expect a precise definition, just references what they have used before.
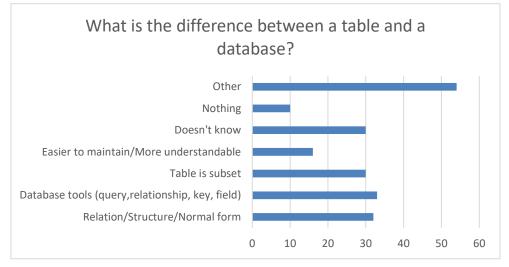
<figure>
What is the difference between a table and a database?

- Other: ~54
- Nothing: ~10
- Doesn't know: ~30
- Easier to maintain/More understandable: ~16
- Table is subset: ~30
- Database tools (query,relationship, key, field): ~33
- Relation/Structure/Normal form: ~32
</figure>

Figure 4: Counted Categorized answers for the second question.

The results for this one were really mixed and interesting. It was really hard to categorize the answers. We think that we were quite kind while figuring out the thoughts of the students. Of course, these answers were not specifically formulated. Just a few examples from the real answers:

- Relation/Structure/Normal form: We can make operation between the tables of a database as well.
- Other: The are more opportunities in a database; A database can be varied in many ways, while a table is more bounded at some level; A database is a table that had data in it; More things can be in a database.
- Table is subset: A database is a collection of tables; More tables

Thus, in the case of categorization, we were trying to categorize the student's reasoning, not the specific answer. Even with is kind method, a very interesting result came out.

The result is very surprising (4th figure), because they have certainly learned spreadsheet and database management in high school, but they do not understand the difference at all.

3.3. Identify where and in what form do you think you will use what you have learned about text editors?

Text/document editors are required in high-school graduation [1]. It is really important to be able to use and understand them, and not just for programmers. There are many general rules and tools that are almost the same in every capable environment (like an e-mail client, in a forum etc.). For example, they will definitely need to write documentations during their future work, where they

will have to use these knowledges, because they will not write it in the Word application. We have no idea whether they know something about the font-, paragraph-, section-level formatting, but it is not that important now. We just wanted to ask if they understand how they will use it. The correct answer would be something generic, not a specific program, tool or purpose, for example: in any software, where I work with a text.
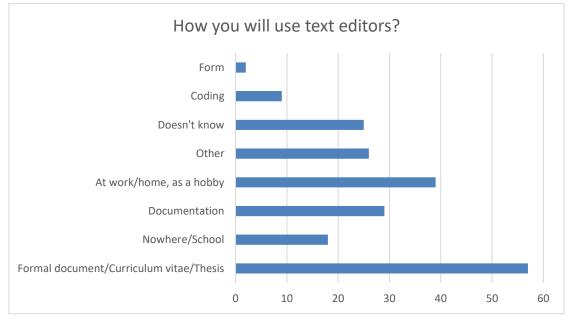

Figure 5: Counted Categorized answers for the third question.

When we constructed the categories, we highly focused if they answered the *In what form* question. Here we were thinking some general text editor item like there must be some font editing option, that follows almost the same logic as Word. As you can see in the 5th figure, only 2 people mentioned that in any way. Just a few examples:

- <u>Other:</u> When I would like to edit some text.
- <u>Nowhere:</u> If I fail my studies, and I will be a secretary.
- <u>Design:</u> Formal editing

In our view, the data clearly indicate (5th figure) that the text editors could not be generally interpreted. There were so many concrete document types (last line), and there were too few that referred to some logic or pattern. What is particularly frustrating is how many people think that nothing is useful in that topic.

3.4. Let's say you need to create a new user in a remote Unix server. Define the general steps that you need to take!
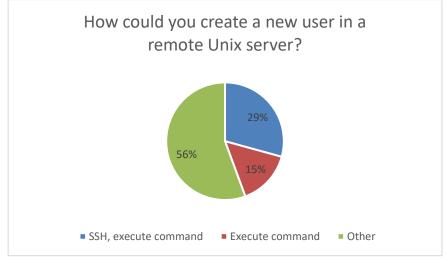
The reason we asked this question is because the shell scripts are currently in the curriculum. In response, we expect is something like:

- SSH connection with the remote server with admin permission
- Executing the right command with the right parameters

They didn't learn how to create a user by using the command line. The point is to make sure that they understand how they will use what they currently learning (the shell environment) and

understand the general structure of what problems they will be able to solve through it. If someone cannot answer this question, that does not indicate that they are not able to pass on the examination, because they just need to use already learned and practiced commands.

6ᵗʰ figure: Counted Categorized answers for the fourth question.

When we identified the results, it was especially true, that completely distant answers were also put into the above categories. For example:

- <u>SSH connection</u>: Connecting to the server, creating the user
- <u>Execute command</u>: Google

Tried to focus on the thoughts of the students. For example, if the answer is "Google", than he/she surely thought about finding the right command.

However, what is clear after understanding the results, is that they cannot identify a problem as a workflow, but they expect something more specific, that connects directly what they have learnt. Of course, we are not saying that they could not solve this problem in real life. We are saying that they had not learn the *system thinking* in the education system, they will do it on their own.

3.5.   Let's say you must create a web-shop. List the layers of the application!

We expected the database-backend-frontend as the right answer. They have met with database and frontend before (high school). They may have not met the backend layer yet, because there is no such subject in the first year of the university. Nonetheless, application layering can be expected from the student, regardless of whether he or she can write queries or not. The hypothesis of course that although it could be expected, but they cannot define the layers, despite they know them separately.
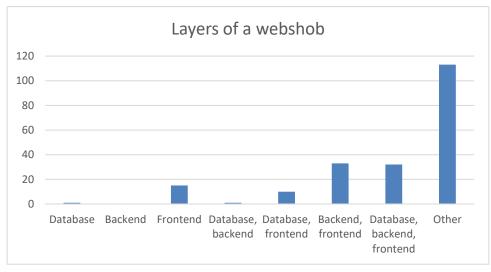
Figure 7: Counted Categorized answers for the fifth question.

The last set of data in the seventh figure includes the answers where there was nothing correlated to layering or it where the student divided the layers in completely different way (e.g.: web page functionality). Since the rest of the data is below the number of responses in the *Other* category, our suggestion was correct. Some examples:

- Database, backend, frontend: Design, servers, storage for goods; Appearance, background scripts, databases
- Database, frontend: Paying software, pictures, prices and products database, data storage database.

3.6. If you had to write a real-time chat application, how would you store and manage your messages?

The question was formulated specifically to give an example where the task is not to learn technology but to connect the technology to a real problem. As an answer we expected any reference to the database. Anyway, this question's strong part is that it cannot be answered without a programmer's thinking. It is already valuable, if the student realize that the answer is an information technology.

Figure 8: Counted Categorized answers for the sixth question.

To be honest, we expected that this question will not prove our hypothesis not least because the first question indicated that it is worth storing information in a database. However, eighth figure shows very nicely that when approaching the problem, they cannot recognize a learned technology yet.

3.7.   True or False? In C++ language, cout writes the given string into the console.

During the first semester, students learn to program in C ++ (as well) so they must know the given function. Of course, the answer is no, because the text will go to the standard output, which is not the same as console. If they use the language to implement basic algorithms, data structures, some general small solutions, they won't see the importance of standard output, just the console to see their small results. Later, it will become more and more important mainly because of the background services and applications (and their output). The issue especially interests us, because shell script writing is also being studied now, where redirection is heavily on the curriculum.
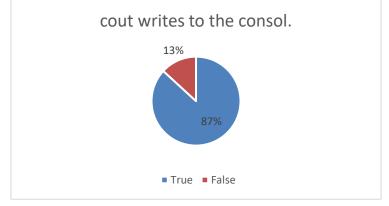

Figure 9: Summarization of the answers of the seventh question

At this question, they had the options, so we should not have to calculate, or categorize, we just counted the answers. The result (Figure 9) is striking students remember the command, they can use it, but they rely on their specific experiences, which are based on specific tasks, but they do no generally understand how it works. Since they have learnt that the standard output can be redirected, they have two coherent, but small knowledge elements, but they are not able to put them together to a system.

3.8.   True or false? There are programs, that can be executed without an operating system.

We were wondering if they understand what happens when they run a program, whether they can distinguish the software from the environment. As they learn to write shell scripts, they have met situations, where the source code is executed by another program, but in other subjects, they learn C++, where the source code is compiled to machine code. The right answer is "true".
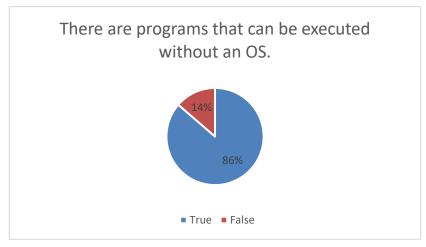
Figure 10: Summarization of the answers of the eighth question

This result (Figure 10) does not prove the hypothesis. The answers indicate that the students may understand what is happening while compiling the program. However, based on the next question's results, we are not sure that this is indeed the case.

3.9.   In what a compiled shell file run? (directly in hardware, OS, Shell framework, Shell program, None of them)

With this question, we wanted to concentrate something current, what they do in their everyday university life. Perhaps, this is the most intrusive element in the quiz. The question itself is meaningless, as the shell script cannot be compiled (it is possible to translate the shell script into a C language and compile it after all, but we cannot expect, that the students met with that tool before) because the shell program will interpret it in real time (the definition of scripts). If the students do not know the answer, than we have a really strong proof for our hypothesis, because this is the thing, that they are currently studying (furthermore, most of them are completing the quiz during the lecture of the shell script subject). We can say that most of the students are able to write shell scripts on their own, so they likely to be complete the subject. On the other hand, it is possible that execution will remain as a black box for them.
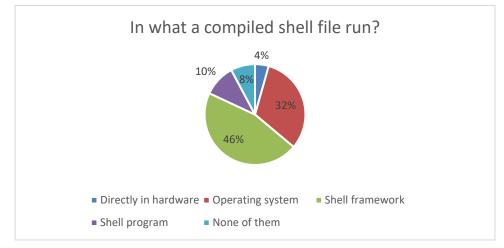

Figure 11: Summarization of the answers of the ninth question (multiple choices)

The result (11th figure) is shocking. We know, that this one was really tricky but even if the students trust the question (you need to compile your shell script), they should have not pick the framework option (as you can see in the 11th figure). For example the "shell program" option can be logical, because it would have mean that they do not remember what the differences are between a program and a script, but they do remember that the shell program will execute their script. During the semester, the corresponding lecture was held by one of the authors (ILLÉS Zoltán), the other (KOROM Szilárd) was also there so we can say that they have never heard about a thing like "shell framework" (in the university). Of course, it is possible, that some of the students have heard about different shell frameworks, but it is close to impossible that it is true for half of the students. Furthermore, it is not true, that a shell script generally executed over a shell environment or framework. All in all, a small amount of answers could be relevant, but definitely not that much.

From the practices, we know that most of the students can write shell scripts on their own, so how is it possible that they have absolutely no idea what is happening when they try to execute it? From the results we conclude that because they are still in the *module* level (questions like writing concrete scripts, define the framework etc.). They can solve a single exercise, because they meet only these kinds of question but usually, we do not talk about the big picture, we do not see the problem from a system level.

3.10. Is it possible to run something that is not a machine code in the CPU?

This item is about the relationship between the hardware and the software layer. We often encounter the question among high school students, how the used application (e.g.: Word) connects to the hardware layer that works with circuits and bits? It is easy to avoid the bottom layer even for a developer, for example if he/she will work with a high-level programming language like java, C#. To sum up, it looks important, but this one does not refer to *systemic thinking*, just a unit question, so we just talk about a basic, pure CPU without any extensions (the question is not about various technologies, but about basic conceptions, if they understand the fundaments).
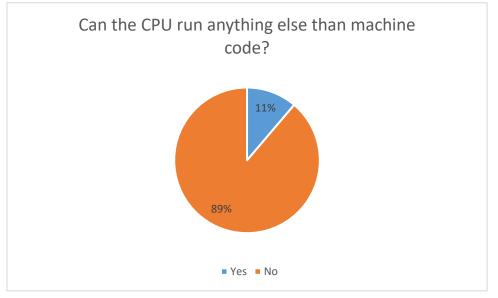

Figure 12 Summarization of the answers of the tenth question

Figure 12 shows that the correct response rate is close to 90%, i.e. if the student receives a question he / she has studied and has to focus on a single unit (not at the system level, but at the level of individual components), than they can make the correct answer.

4. Conclusion

We think that we could prove the original hypothesis, that even if the students know a *module*, they not necessarily can applicate it in a *systemic level*. The correct answer rate was close to 90% for the last question, which asked for a *module level* knowledge (12th figure). We have only one exception from the other items, where the students could not make the correct answer. In our opinion, the answers indicate many further questions (why they think that there is a thing like "shell framework"). We also had some shocking results.

We had to make categorizes for short answer needed question, but we would like to note, that it is possible, that other categorizes with different rules from different aspects could also be meaningful. For example, we also asked their programming experiences but in the context of the article we felt it was not possible to examine the answers in the light of this.

At the beginning of this study we tried to give border, technologies, methodology, that is applicable to step out from the *modules* into the *systemic thinking*. An IoT system drives the students to problems, where they must use several *modules* at the same time in order to build a complex working system. For example, they should have use database for building up real-time communications, connecting to the small devices without GUI, they made documentations and they also presented their solutions, they had to design a software system, so they could use different architectures. All in all, they were forced to build up an end-to-end solution with all its difficulties.

In general, a possible curriculum can be made for the different topics, what are scalable, the focus points are movable based on the students ages and knowledges. Proving that this is indeed effective has not yet happened, but it may in the future.

Acknowledgement

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