EDUCATING ENGINEERS FOR RESEARCH-BASED INNOVATION – CREATING THE LEARNING OUTCOMES FRAMEWORK

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ABSTRACT

Skolkovo Institute of Science and Technology (Skoltech) is a newly established graduate university in Moscow, Russia, with the knowledge triangle mission to educate students, advance knowledge, and foster innovation in order to address critical scientific, technological, and innovation challenges and gaps facing Russia and the world. Educational programs will therefore be designed to foster the graduate qualities that are needed for research, innovation and entrepreneurship. In order to develop a broad consensus around the educational mission of Skoltech, we engaged stakeholders to better understand their needs and the appropriate mission of Skoltech education in the triple helix ecosystem. Preliminary high-level learning outcomes were formulated, drawing on a workshop with stakeholders and on reference frameworks, among them the CDIO Syllabus. The preliminary learning outcomes were discussed in depth with stakeholders from industry, universities, research institutes and governmental organizations in Russia, EU and USA. This paper analyses the input from 38 stakeholders and presents the resulting Skoltech Learning Outcomes Framework.

KEYWORDS

Learning outcomes, stakeholder analysis, education for innovation, post-graduate education.

INTRODUCTION

Founding a New University for Impact on Society

Skolkovo Institute of Science and Technology (Skoltech) is a new graduate university in Moscow established for the mission to *educate students, advance knowledge, and foster innovation in order to address critical scientific, technological, and innovation challenges and gaps facing Russia and the world*. This mission reflects ambitions to generate positive economic and other societal impact from research-based innovation. To achieve that purpose the three fundamental functions of the university – the knowledge triangle of research, education and innovation – should be closely integrated [1]. The importance of education is emphasized, based on the insight that university graduates are a key mechanism for bringing about entrepreneurial impact in society [2].

A university *organized around innovation* is a new category in the higher education of most countries, and Skoltech as an educational institution is intended to serve as a new model. Naturally, the demand is high in Russia for new generations of well-educated professionals to further enable and drive the development of the market-driven economy created through liberalization and privatization after the Soviet Union. As the current Russian economy is very strong but overly relying on natural resources, in order to increase global competitiveness and economic resilience it is necessary to grow additional economic bases through innovation and entrepreneurship. An education aiming to prepare the graduates for science and technology-based innovation thus needs to be very different from education of specialists for more routine tasks. The Skoltech education must bring together the scientific and technical fundamentals necessary for innovation, with knowledge in the innovation process, and the skills and self-confidence necessary for leading innovation and entrepreneurship. Skoltech is founded to be the *engine of an innovation center* currently being grown in Skolkovo, as a part of the on-going economic and social modernization of the Russian Federation. A key strategy is to redefine the interface between public and private sector, aiming at an open innovation ecosystem with intimate and dynamic collaboration within the so-called triple helix of academia, private companies and public organizations [3]. In Skolkovo students will be a part in this dynamic market-oriented high-tech environment already during their education – they will live in it.

It is not only the close connection between education and innovation that sets Skoltech apart in the Russian higher education landscape, but so does in fact already the close integration of research and education. As a *research university* it represents a new structural model, because engineering education and research have historically been quite separate in Russia. Universities are mostly dominated by undergraduate education, while research and research education takes place chiefly at institutes of the Russian Academy of Science. Because university rankings are based on a composite of indicators related to research and education, it is a clear sign of this separation that, typically, only two Russian universities rank in the top four hundred [4]. Skoltech is a purely post-graduate university offering the Master and PhD degrees. Integrating education with research is intended to provide graduates with cutting-edge knowledge and competence.

Another keyword for the Skoltech endeavor is *internationalization*. For historical reasons, Russian higher education has been comparatively isolated and it is still a high priority to increase international exchange and recognition. Skoltech is founded in collaboration with Massachusetts Institute of Technology (MIT), which will assist in building the faculty and defining and implementing the overall university structure and curriculum. Faculty capacity is built through the establishment of centers composed by international research groups in partnership, forming a highly international scientific environment. To ease student mobility, education is aligned with the European Higher Education Area (created by the Bologna process). Skoltech will thus be a portal for international mobility for faculty and students. The university and the Skolkovo ecosystem around it will serve as a dynamic and attractive environment. The aim is increased international mobility with a healthy circulation, balancing outgoing and incoming streams.

Finally, while Russian undergraduate education deservedly respected worldwide for its high standards, particularly of theoretical abilities in mathematics and physics, stakeholders express the need to achieve change in the higher engineering education, in terms of the *teaching and learning processes* as well as the resulting *graduate abilities* [5]. Such desire to improve higher engineering education is not unique to Russia, but consistent with international accounts where stakeholders express their needs [6]-[10]. Starting a new university from the ground up is an opportunity to implement education in ways that can be harder for existing institutions that need to change deep-rooted traditions and organizational inertia.

It is in the light of this complex background that we set about to design the intended learning outcomes for Skoltech. The conclusion is that educational programs have to foster the knowledge, skills, and confidence necessary to undertake and lead research and innovation.

Methodology for Curriculum Design

The process for curriculum design at Skoltech is based on the outcomes-based top-down methodology developed in the CDIO Initiative [11], as defined by twelve dimensions of educational development, the CDIO Standards [12]. The starting point is to formulate a high-level vision of the graduates (Standard 1) and to translate this vision into learning outcomes validated with stakeholder needs. Then, specific and detailed learning outcomes can be developed for programs in different domains (Standard 2). Next, program learning outcomes are assigned to curriculum elements – be it courses, projects, or other credit bearing activities (Standard 3). These are then designed to achieve and assure students' attainment of these intended learning outcomes [13] through appropriate teaching and learning activities and assessment procedures (Standard 7 and 11).

In this paper, we describe the first step of the process, the creation and validation of the Skoltech Learning Outcomes Framework. Its purpose is to express the educational mission on such level of concretization and detail that it can serve as the reference document for curriculum development – a framework for formulating appropriate learning outcomes on program as well as course level. It serves the same function in curriculum development as the CDIO Syllabus [14]-[15], but the content is customized for the particular educational mission of Skoltech.

PROCESS FOR ESTABLISHING THE DESIRED LEARNING OUTCOMES

Designing a Preliminary Framework

The first step in the educational development process was to organize a two-day forum focused on expressing the needs of Russian stakeholders and formulating a vision for the desired attributes of Skoltech graduates. Participants represented Russian industry, universities and research institutes, international expertise on education, and MIT faculty, in total almost a hundred participants. Synthesizing two days of discussions, a preliminary set of learning outcomes was formulated, with the aim to be comprehensive and inclusive of all this rich input.

Drawing on previous relevant work the learning outcomes were logically organized into a framework with the same major areas of knowledge, skills, and attributes as the CDIO Syllabus [14]-[15] and the UNESCO Pillars of Education [16], and encapsulating the leadership dimensions of the Capabilities of Effective Engineering Leaders: *Core Personal Values*, *Relating*, *Making Sense of Context*, *Visioning*, and *Delivering on the Vision* [17]. See Table 2. In the framework, sections 2-4 are intended as general institution-wide learning outcomes to be applicable to all programs at Skoltech. Each item in those sections are exemplified and explained with sub-bullets (not listed in this paper). Section 1 is to be considered as a placeholder for the domain-specific learning outcomes to be defined for each program.

Stakeholder Interview Study

To refine and validate the learning outcomes, more stakeholders were engaged in discussion and evaluation of the proposed high-level goals of Skoltech education. Interviews were made in

April-October 2012 with 38 representatives of industry, research/educational institutions and governmental organizations in the IT, Nuclear, Space, Biomedicine and Energy sectors. See Table 1. Senior managers, in most cases the CEO, were engaged in conversation one-to-one.

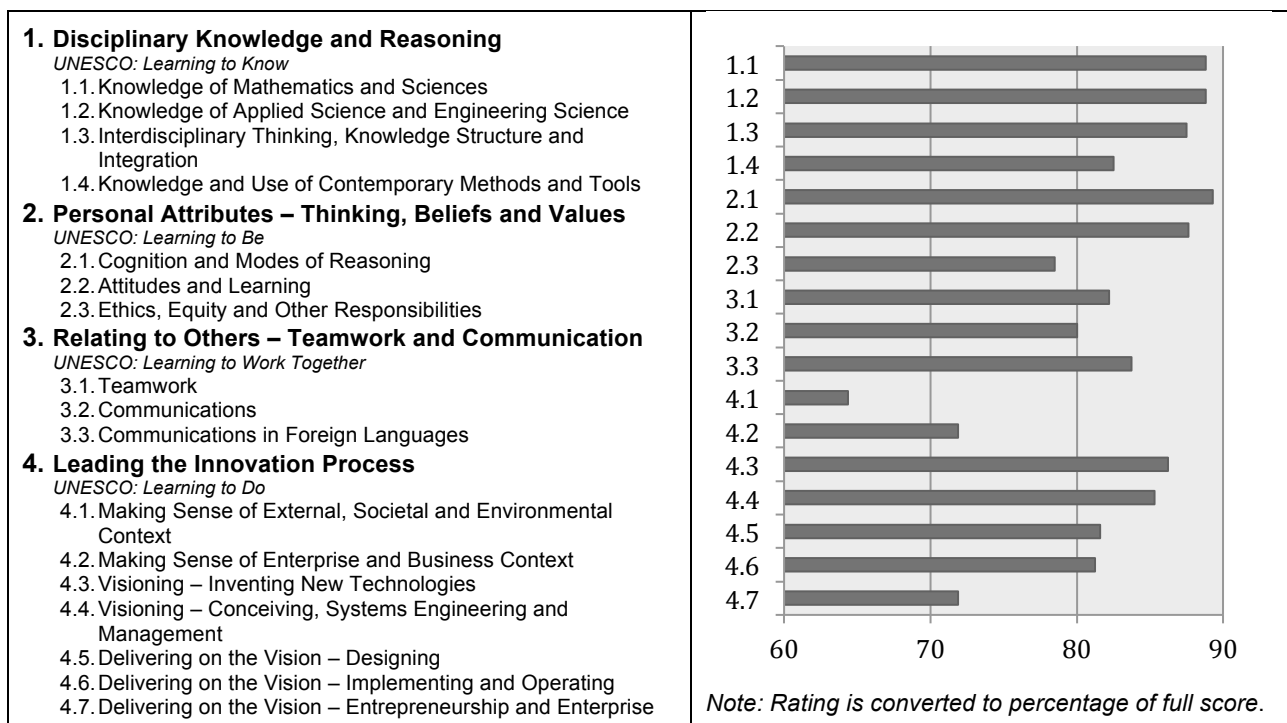Table 1. Distribution of Stakeholders by Type and Region.

Distribution of stakeholders by type	Distribution of stakeholders by region
14 Large companies (>5000 employees)	22 Russian companies and organizations
6 Medium-size companies (100-5000 employees)	7 International companies based in Russia
5 Small start-ups companies (<100 employees)	4 Based in Europe
9 Research/educational institutions	5 Based in the USA
4 Governmental organizations	

Respondents were first asked to express their own vision of desired qualities of engineering graduates. The open-ended part of the interview lasted from 40 minutes to two hours, and was recorded, transcribed and (if necessary) translated to English. Finally they were asked to rate the preliminary learning outcomes (above). The rating scale was created as a hybrid scale combining the *importance,* a scalar quantity suitable for a Likert scale, with the desired *levels* of learning outcomes, in qualitative steps inspired by the Feisel-Schmitz taxonomy [18]:

> 5 – Essential – able to exercise advanced judgment and develop new approaches
> 4 – Highly important – able to solve new problems by application of principles
> 3 – Important – able to explain the underlying theory or principles
> 2 – Moderately important – able to solve problems by following established procedures
> 1 – Slightly important – able only to describe facts and concepts
> 0 – Not important – no knowledge or understanding is necessary

RESULTS FROM CONSULTATIONS

Table 2. Preliminary Framework and its Rating.

1. Disciplinary Knowledge and Reasoning
 UNESCO: Learning to Know
  1.1. Knowledge of Mathematics and Sciences
  1.2. Knowledge of Applied Science and Engineering Science
  1.3. Interdisciplinary Thinking, Knowledge Structure and Integration
  1.4. Knowledge and Use of Contemporary Methods and Tools
2. Personal Attributes – Thinking, Beliefs and Values
 UNESCO: Learning to Be
  2.1. Cognition and Modes of Reasoning
  2.2. Attitudes and Learning
  2.3. Ethics, Equity and Other Responsibilities
3. Relating to Others – Teamwork and Communication
 UNESCO: Learning to Work Together
  3.1. Teamwork
  3.2. Communications
  3.3. Communications in Foreign Languages
4. Leading the Innovation Process
 UNESCO: Learning to Do
  4.1. Making Sense of External, Societal and Environmental Context
  4.2. Making Sense of Enterprise and Business Context
  4.3. Visioning – Inventing New Technologies
  4.4. Visioning – Conceiving, Systems Engineering and Management
  4.5. Delivering on the Vision – Designing
  4.6. Delivering on the Vision – Implementing and Operating
  4.7. Delivering on the Vision – Entrepreneurship and Enterprise

Note: Rating is converted to percentage of full score.

Results for Section 1. Disciplinary Knowledge and Reasoning

*S*takeholders expect Skoltech graduates to possess the highest level of *Disciplinary Knowledge and Reasoning*. Strong fundamentals are a hallmark of Russian education and Skoltech is expected to live up to the same high standards; it is clear that nothing less will do. An ideal graduate combines a strong foundation of perennial theoretical fundamentals with the most up-to-date and cutting-edge science and technology knowledge.

- *"People with the knowledge we are looking for are rare. Not only in Russia, they are rare worldwide."*
- *"They need to have sound fundamental education, excellent basic skills, that is what we need to maintain and keep, because in this respect we are more advanced than the West."*
- *"Old school math and physics that we have is great. But we have had stagnation and much of the modern front-line developments of the past 20 years have practically escaped us. Today's technology is moving very quickly. If you have good fundamental knowledge and get into the right environment, you will learn it very quickly."*

Theoretical knowledge in itself is not enough, however. Graduates need the ability to apply the knowledge to work on real problems, to formulate and define problems, to make interpretations of problems in a context. One stakeholder in the IT field puts it well:

- *"We want people who can solve real world problems. Beyond just programming, the ability to model real life, do models and solve them. To see a problem and try to formalize it, and find the solution. What is important, the person should be able to map real life problems to mathematical models."*

Stakeholders note how the ability to apply knowledge and methods is related to the person's attitude and self-efficacy (in Section 2). In order to foster such intellectual courage, the culture of the institution must allow for hands-on learning, for practice, and for risk-taking and failure. Skoltech must create an atmosphere safe for trying, and safe for being honest about ones results. The desired *absence of fear* must be engrained in the educational experience:

- *"Education isn't just a pile of knowledge in your head; it's a procedure of solving any problem, its approach and absence of fear to solve this problem."*

Interdisciplinary Thinking, Knowledge Structure and Integration is seen as necessary for applying disciplinary knowledge in practice, and is the third highest rated item in the whole list. This has implications for the design of Master programs, because connecting the knowledge in an interdisciplinary structure cannot be left to the students. Each subject must continuously make connections to foster interdisciplinary understanding, further reinforced through practical learning experiences where students are required to cross the disciplinary boundaries to address realistic problems.

- *"In engineering students receive a separate course in materials, a separate course in math, a separate course in something else. This subject 'separatism' gets into their heads; it doesn't give the opportunity to complete the global picture. Students need to try out, apply, all the knowledge. Students should perform a set of realistic projects, not alone but in teams. To compile those separate fragments of knowledge they should get into situations where they can actually use them."*

The conclusion of stakeholder engagement for Section 1 is that these learning outcomes are strongly supported and expectations are high. We can safely conclude that it is completely unthinkable to stakeholders that Skoltech graduates would have any weaker command of fundamentals than the best graduates from other Russian universities. In the final framework (see Appendix 1), the only change in Section 1 was the addition of a new category for lead-in knowledge *about* innovation and entrepreneurship. It was noted that innovation is not just a skill as it is described in Section 4, but that there is also a body of foundational knowledge.

Results for Section 2. Personal Attributes – Thinking, Beliefs and Values

Cognition and Modes of Reasoning had the highest rating in the whole framework. They are seen as foundational skills, the cornerstones that any other skills rest upon. Many stakeholders wanted to discuss and emphasize particular aspects, and *creative thinking* was often singled out as particularly needed.

- *"Our first and most important value is intellectual discipline, the ability to think."*
- *"Ability to think creatively! To think about the future shape is not to reproduce some old wisdom that comes from old guys who already did everything."*
- *"Creative thinking, to understand how to take this and do something. A person with natural curiosity is always full of ideas and thinks of ways to implement something."*
- *"They should be naturally curious. And they should be able to admit their mistakes."*

Also *Attitudes and Learning* is very highly rated. Stakeholders offer many insights related to the qualities for continuous learning and personal development:

- *"…passion in the eyes and a desire to achieve something in life, that is, the ability to learn after graduating."*
- *"…ready to permanently stay in 'constant innovation' mode since technology changes rapidly."*
- *"That's the first thing - just to be really thrilled by the self-education process."*
- *"Curiosity, creativity, and a willingness to experiment and iterate. You need to see what exists and wonder what else could exist. You want people with a developer's stance. Coming out with a range of alternatives. Not to view it in a deterministic way, of right or wrong. We need a mindset of iterations."*
- *"We are expecting the people to be innovative and self-organized, and understand that there isn't a manager who takes care of them like a baby. They have to be pro-active, and take care of themselves. It is a little bit missing in graduates from Russian Universities. I would not say that this is taught in [universities in other countries] but the whole society is requiring it from the people."*

Clearly, qualities like independence are seen not only a result of education but partly also fostered in society as a whole. They must thus be encouraged and developed through the full educational experience and the Skolkovo environment. Faculty and all other people the students encounter during the education are important role models, because the only thing more contagious than "passion in the eyes" is the lack of it.

We notice that *Ethics, Equity and Other Responsibilities* is rated particularly low and it is noteworthy how seldom these qualities are mentioned in interviews.

- *"[Russians] are used to a broader concept of moral broken down by social groups, a moral that has many shades. Bribes, offerings, services… And there is nothing you can do about that. Foreigners fail here because they don't understand that they got into a society without protestant moral."*
- *"You should have some solid core, some moral responsibility inside. We work with strong forces of nature, which will never forgive me if I take the easy way out. I should be responsible, not the fear that my boss will fire me, the responsibility to yourself, to the society and your grandchildren. You should have this feeling inside yourself that some things are unacceptable. It is unacceptable to sweep this dust under the carpet, I won't sleep well for the rest of my life."*

The conclusion of stakeholder engagement for Section 2 is that these learning outcomes have the highest support. The exception is the item *Ethics, Equity and Other Responsibilities* which has lower support. This finding is somewhat surprising; as for instance corruption is a known problem in Russia [19], a seriously impeding factor for internationalization. In efforts to increase economic stability and growth, the level of trust will affect the willingness to make long-term investments. Skoltech must be a positive factor in this respect, contributing to an environment where business can be done with a higher level of trust. Therefore, in the final version of the framework (see Appendix 1), Section 2 remains as it was formulated in the preliminary version.

Results for Section 3. Relating to Others – Communication and Collaboration

For Section 3 there is some contradiction between qualitative and quantitative data: while communication and collaboration skills are not the highest rated items, these are the qualities that stakeholders discuss with the greatest possible enthusiasm. In describing the uniqueness of Skoltech education this is where they attach the highest importance.

Stakeholders discussed the power and necessity of *Teamwork,* and collaborative working modes in general, with much sophistication. They identify the importance of the attitude components ("skills <u>and desire</u> to work in teams"), and clearly note how collaboration skills are highly interwoven with communication skills.

- *"A desire to communicate and be a team member, a spirit of team players, social interaction is something which produces a new dimension of the work the people are involved with."*
- *"A modern university should prepare teams. This is true for both management and engineering specializations. This is true for any intellectual work. We should not prepare separate people, but research or engineering teams. There is a set of skills that have to be inherent to every single graduate, allowing them to fit into teams, lead them etc. In my opinion, this is the principal quality."*
- *"Most important is the ability to work on a team. To not push a lot, but the ability to listen to others."*
- *"They need experience in team work. It's important to see how much a person is prepared to work in a team. Practice shows that people who prefer to do everything themselves do very poorly in a company. They might have a higher IQ level, but they narrow down their communication circle a lot. It's very important to hire people who can successfully communicate with each other and share ideas."*
- *"Communications are a bit different. This is a resource within the scope of cooperation tasks. If a person graduates and can cooperate, he has a patent to be an engineer. If he graduates and can't cooperate, he will never be an engineer. He won't even be able to enter cooperation. What is the main problem of this country? Nobody knows how to cooperate. It is a major problem! You can only teach cooperation if you put a person into a situation of cooperation."*

The emphasis on teamwork skills does not mean that everyone needs to be cast in the same smooth shape, however. Inside teams there is room for different characters:

- *"Quite often the star performers are rough at the edges. They are not smooth and easy people, but they are star performers. That is they're mavericks. If you have a few people like that in your team, it's not a problem. If everybody is weird then you have a problem; but if you have a mixture of normal people with a couple of utmost geeks who are geniuses - but weird ones - that's fine."*

Communication skills are mentioned in most of the interviews as highly important qualities that are urgently needed. Many stakeholders state that the level of communication skills developed in the Russian education system is insufficient. There is a widespread enthusiasm among the stakeholders that Skoltech can create a learning experience to develop these skills.

- *"The ability to get your thoughts through to other people is a quality. It is important to be able to shape your ideas, thoughts, and achievements as a finished product, no matter if it is a document, a presentation, an article, a monograph or a speech. To know how to not only achieve a result, but also how to present it, to make a 'candy' out of it."*
- *"They have to be credible."*

Stakeholders give particularly rich and insightful descriptions of the abilities relevant for communication. They paint a complex picture, showing that this is not just about techniques, but also includes the underlying ownership and independence, a trust in the environment, a courage. This suggests that the communication skills are not only an attribute of an individual. To some extent communication skills are also embedded in the social and cultural context. In a highly hierarchical culture, it may be the lack of empowerment that prevents people from speaking confidently, rather than the lack of skills per se.

- *"Russians would prefer not to be bothered when asked to share some ideas. First of all, they don't know how to do that, except to write a code or draw something, etc. They really may be afraid that*

their ideas may become stolen. Also, Russian culture is very hierarchical. If the leader doesn't permit you to say something, people prefer to be quiet and not express themselves. Again, it comes down to the social environment, the level of trust. We really want to stimulate that trust. What we really want Skoltech to do is just to allow these people to grow and to show them the path to grow."

▪ *"Communication skills are just an element. To communicate something you need to have something to communicate. Not like: 'I'm doing this because my scientific advisor told me to do so'. It's about the idea that 'what I'm doing today has ultimate importance, and investing efforts into selling what I'm doing isn't worth spending time and energy'."*

Within *Communications in foreign languages*, only English is emphasized. No stakeholder demands any additional foreign language. English is necessary to make work processes efficient. This stakeholder describes the language barrier as something that impedes operations, not just for the persons themselves, but for the whole organization:

▪ *"Anybody whose English is not ideal, has a problem. That's a really serious problem for everybody. And practically they need you to sit down to translate. Even if they can communicate somehow, they are still missing something and that something we are losing from our results, our load, our force."*

One of the most important findings is how strongly stakeholders emphasize communication skills for the international settings. This comprises much more than just the language skill itself, but also the ability to work across cultures. An international experience is often suggested as necessary for developing the confidence and sensitivity to be able to work in multinational environments. It is strongly emphasized by several stakeholders that these abilities are important to open up the global markets to Russian actors, and Russia to the world. The impression is almost that if Skoltech only gets this aspect right and prepares graduates for international interaction in Russia and abroad, it has fulfilled an important purpose:

▪ *"We understand that there aren't any 'national' markets – there is only the global market. A person must be able to work in multicultural environment. It doesn't only comprise international ones, but also in different language environment."*

▪ *"When we put teams together to solve specific issues, people have different skills in different areas. They are also in different time zones and have logistical problems in interacting, there are cultural problems, problems of understanding each other – it takes time. But if students have already been exposed to this and have opened their minds, they are less afraid of different viewpoints based on culture and history, language issues. Companies need to secure that we work well across borders. Skoltech has a big potential of making something very, very different in Russia."*

Collaboration and communication skills, including language and intercultural competence, are important to get the work done, but they are also seen as modes of continuing professional development. The lack of such skills has consequences for careers and lifelong development:

▪ *"They have to bring their words into an external audience. We believe it's important because if you don't socialize, if you don't test your ideas, if you don't share your experience, you are not ready to pitch your story. It means that you're vulnerable, and when people get vulnerable they get even more condensed and unlikely to expose themselves to the outside."*

▪ *"Russians are often not offered international assignments because they don't speak fluent English. Most of them don't know how to socialize with different people, different cultures and nations. They feel afraid: 'How am I going to speak to these Indian guys?' The English language level might be the same, but still they don't know what to talk to them about. So they stay here, and don't grow professionally if they don't get an extra assignment. That's a critical item for us. People have to know how to work in international teams, how to express themselves, how to flash new ideas."*

Such negative descriptions can easily be translated into their positive opposite. Practicing communication and collaboration in an international environment, will equip Skoltech graduates for a career where they keep developing professionally through these modes of working together.

The conclusion from stakeholder engagement in Section 3 is that excellent communication and collaboration skills clearly constitute a major expectation on Skoltech graduates. The categories

in the preliminary version of Section 3 did not fully reflect stakeholders' sophisticated views on these skills; as profound skills with implications for a person's professional capacity as well as a means of future development. In the final framework (see Appendix 1), the changes in section 3 were profound. First, as the label *Teamwork* did not capture the width and depth of stakeholders' insights and intentions, it was split into *Teamwork* and *Collaboration and Change.* Further, as it was obvious how international communication depends on much more than the language skills per se, it was changed to *Communications in International Environments*.

Results for Section 4. Leading the Innovation Process

Section 4 outlines qualities associated with understanding the needs in society and leading the process of bringing research-based innovations to the market. The learning outcomes that are most associated with the technology itself were top rated, while those associated with society, market, business and entrepreneurship, were rated lowest in the whole preliminary framework.

Skoltech graduates are expected to be future leaders in innovation and research, in industry as well as academia. Many stakeholders describe a graduate with practical skills in leading engineering projects, by which they mean the ability to get things done.

- *"Now there is the ability to do things."*
- *"A sound grounding in their profession, science or engineering."*
- *"Leadership is not only having a group. It is to really, really foresee what the future needs are, and influence a group of people around you to go in that direction. That's what leadership really means."*
- *"Leadership is not to say: 'I've listened to all your views and this is how we're going to do it', but rather a leadership that says: 'Let's define the problem together', so that all the people can see their contribution. This is how you build the team."*
- *"Leadership is to move the whole thing forward instead of a one-person agenda."*
- *"Teamwork is equally important in research, because of the interdisciplinarity of the research and dealing with more complex problems."*

The Skoltech mission is to provide education for innovation. The term innovation encompasses the full process including successful entrepreneurship, commercialization, or achievement of other forms of impact. This is an important point to stakeholders and expectations on Skoltech as an engine in the innovation ecosystem is clear:

- *"Innovation is to generate money, to generate profit, to have a good idea and generate profit. Invention is a different story – you burn money. There is a great idea and you spend money on it. Very, very, very important; people are often talking about innovation but if you listen it is not innovation; they are talking about invention. They have a super-duper clever idea. But what is the product?"*
- *"They need knowledge in how to apply what they know to real-world problems, and then how value is created through innovation. The potential for new ways to make value. It is a balance that is needed, not just specialization and hoping some other people will do all the other stuff."*
- *"A professional education in 'entrepreneuring' – that is the doing part of entrepreneurship."*
- *"If you don't have any cost limits, you can produce anything. But with limits – in real projects you always have limits – then it drives knowledge and innovative thinking among students."*
- *"Success in taking new concepts in academia and working with the private sector to turn it into a successful product. This is the missing link in Russia; the gap that Skoltech is designed to fill. Economy is more in commodities and resources. It needs diversifying and new products, new production and taking a market share of hi-tech production."*
- *"If you want to educate entrepreneurship, you should confront students with entrepreneurs and try projects with the possibility to start a company or creating something really new. If you want to learn to swim it's a great advantage to have water, right?"*

Creating value for society and contributing to a sustainable development is emphasized as an important context for innovation. This has deep implications for education.

- *"Eager and capable to learn, a broad understanding of the environment they're living in."*
- *"Ability to understand how to contribute to sustainable development is crucial, a broader view than the specific subject. When you have environmental or societal or another context in mind, you will be also much more prone to be visionary and that stimulates the ability to come up with innovative things, because innovations occur when you are at a crossroad between different viewpoints. If you only dig deeper and deeper into your specific field of study, you will not contribute to the innovation system."*
- *"Sustainability is a very important question. You have to think ahead, ask yourself – is that useful, what I do, is it sustainable, is it good for the environment? And you have to learn that early. It is part of today's education, it must be."*
- *"Analytical skills, leadership skills, complex problem solving, design, teambuilding… it is all going to be interdisciplinary and it has to be put in a social and economic context. Technology in itself is not a solution, it is only a means, and it has to be put in an appropriate context to be a complete solution."*
- *"The primary purpose to establish a new university is to be a change master in taking the new concepts into products and processes for the marketplace, but also to solve complex problems that address national needs."*

In stark contrast to the lower ratings, many comments are made about how it takes a different mindset to develop technology with a market-driven approach. Some mention a tendency in engineers to overemphasize the technology in itself and fail to understand the market needs and conditions. This has implications also for the disciplinary knowledge. Stakeholders remark on a status hierarchy in academia where some newer disciplines are not valued as highly as the traditional ones, despite the volume of the market that they generate.

- *"Even at the best Russian schools, thinking about mobile applications for Google phone is not seen as something serious, worth spending time and effort on. At [department], you should think about space stations and how to make the connection, or a nuclear reactor smoldering. Things like that are worth spending mental energy on, but App Store doesn't really matter."*

Innovators need to fully understand that the market ultimately makes many decisions. If one's education, status and identity are attached mostly to the technology itself then there is a tendency to optimize the technical process rather than to optimize the value for the market.

- *"In Russia, marketing used to be associated with guys who don't know much. The stereotype was guys who are pretending, talking smart words. What I mean now is a different kind of marketing, which is responsible and really can drive, which is close to leadership. The art team should make decisions on features – they know what would make an easy-to-use product, they are closer to the customer. These decisions cannot really be based on how easy it is to develop the product."*

It is also worth remembering that in the Russian society, the modern market economy, and thus the meaning of a market-driven approach, is relatively new:

- *"Business acumen [is most important]. First of all, understanding that not only the state can be the ultimate customer. The end customer in many occasions, more and more so, is a consumer."*

The nature of personal motivation and ambition for entrepreneurship is mentioned as an important factor. Stakeholders point out that creating enterprises that last and expand require a long-term commitment, and the desire to achieve something beyond just a quick personal profit.

- *"Motivation for creative work, motivation to work for results (not just for personal enrichment)."*
- *"You'll see solidly good entrepreneurs in Russia, but very few of them really have any idea of conquering the world. US entrepreneurs really think globally: 'We want to take it all'. Russian guys say 'No no no! I just want to start a startup, wait a couple of years, best case scenario sell it as quickly as possible, 3-5 years maximum'. Nobody wants to spend their whole life in their business and get involved. We want this ambition."*

A few stakeholders discuss research skills, and then it is research with a consideration for use that is emphasized, and so is the intimate connection between education and research expected of Skoltech:

- *"Research in industry is always application-driven. That means there must be an application mindset, it's not about fundamental research."*

- *"The form of their introduction to research cannot be in the form of an observer. They have to be included in real research: they have to take a position and start living. Only then will they start to understand something and really study something – not just say that they are."*

The conclusion of stakeholder engagement for section 4 is that the learning outcomes associated with innovation have strong support among stakeholders, and support is stronger the closer the learning outcomes are to the technology. There was a tension between quantitative and qualitative data for the other aspects, associated with society, market, business and entrepreneurship. Despite low ratings, when stakeholders discussed innovation, it was with almost all attention to societal, business and market aspects, and in fact this was often seen as the missing link, the very gap that Skoltech is created to bridge.

In the final framework (see Appendix 1), the Section 4 was reworked. A common reaction to the preliminary framework was that it was overly detailed. Therefore, some items were merged and at the same time some important aspects were emphasized more clearly. The two items associated with making sense of the context were merged into one, and the concept *Global* was added, resulting in: *4.1 Making Sense of Global Societal, Environmental and Business Context*. It was emphasized that *research* is the basis for innovation, resulting in *4.2 Visioning – Inventing New Technologies Through Research*. The two items related to *conceiving* and *designing* were merged and the importance of *sustainability* was made much clearer, resulting in *4.3 Visioning – Conceiving and Designing Sustainable Systems*. Only the two last items remained unchanged.

FINAL COMMENTS

Using the Learning Outcomes Framework

The Learning Outcomes Framework whose creation was presented here is *comprehensive* in that it encompasses all major categories of learning outcomes that Skoltech programs and courses will be designed to fulfil. It is however not intended to be prescriptive in its entirety, that is, every program will not aim to fulfil every learning outcome to the same degree. Rather, there will be good reasons to define program learning outcomes with slightly different emphasis within this framework, either for different domains or intended for different graduate roles. Individual students will further be able to position themselves according to their own interests and specialize within this space of opportunities.

The next step in the curriculum design process is to define learning outcomes on the program level, for programs in different domains. Thereafter, learning outcomes are formulated for each curriculum element (courses, projects, or other credit bearing activities), explicitly assigning to each course a responsibility to contribute to the program learning outcomes.

Interpretations and Tensions

Validating the intended learning outcomes with stakeholders is an important part of the educational development process. But for several reasons there will and should be tensions between the desires expressed by stakeholders and the informed decisions made by the university. Education has by its nature a considerable lead-time – we educate graduates who will solve future problems, creating and using future technology, creating and being active in future markets. Therefore, education always has a dual perspective. The qualities of Skoltech graduates should support and enable these stakeholders in achieving their missions, but at the same time the graduates should also contribute to driving the development and contributing to

change; they are expected to be change agents. In other words, it is important to interpret the stakeholder views, and make a careful analysis before the university makes its informed but independent decisions. This means that in some respects our aim is indeed to go further than the stakeholders expressed, and also to provide things that some of the stakeholders did not or could not wish for. Examples above include ethics, making sense of societal and business context, and the entrepreneurship and enterprise skills necessary for delivering on the vision. Henry Ford expressed it bluntly: "I*f I had asked people what they wanted, they would have said faster horses*". This tension is particularly relevant in the case of Skolkovo Institute of Science and Technology, because it is a new kind of university founded with a mission to provide graduates of a different kind – our institution and our graduates are intended to *be the change*.

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**Appendix 1. Skolkovo Institute of Science and Technology:
Learning Outcomes Framework for Science, Engineering and Innovation Leadership.**

1. DISCIPLINARY KNOWLEDGE AND REASONING

UNESCO PILLAR: LEARNING TO KNOW

1.1 KNOWLEDGE OF MATHEMATICS AND SCIENCES
1.2 KNOWLEDGE OF APPLIED SCIENCE AND ENGINEERING SCIENCE
1.3 KNOWLEDGE OF INNOVATION AND ENTREPRENEURSHIP
1.4 INTERDISCIPLINARY THINKING, KNOWLEDGE STRUCTURE AND INTEGRATION
1.5 KNOWLEDGE AND USE OF CONTEMPORARY METHODS AND TOOLS

2. PERSONAL ATTRIBUTES – THINKING, BELIEFS AND VALUES

UNESCO PILLAR: LEARNING TO BE

2.1 COGNITION AND MODES OF REASONING
- Analytical reasoning and problem solving
- System thinking
- Creative thinking
- Decision making (with ambiguity, urgency etc)
- Critical thinking and meta-cognition

2.2 ATTITUDES AND LEARNING
- Initiative and the willingness to take appropriate risks
- Willingness to make decisions in the face of uncertainty
- Responsibility, intensity, perseverance, urgency and will to deliver
- Resourcefulness, flexibility and an ability to adapt
- Self-awareness and a commitment to self-improvement, lifelong learning and educating

2.3 ETHICS, EQUITY AND OTHER RESPONSIBILITIES
- Ethical action, integrity and courage
- Social responsibility
- Equity and diversity
- Trust and loyalty
- Proactive vision and intention in life

3. RELATING TO OTHERS – COMMUNICATION AND COLLABORATION

UNESCO PILLAR: LEARNING TO WORK WITH OTHERS

3.1 COMMUNICATIONS
- Communications strategy and structure
- Written, electronic and graphical communication
- Oral presentation and discussion
- Inquiry, listening and dialogue

3.2 COMMUNICATIONS IN INTERNATIONAL ENVIRONMENTS
- Communications in English in scientific, business and social settings
- Effective interaction in different cultural and international settings

3.3 TEAMWORK
- Forming effective teams
- Team operations and project management
- Team coordination, decision-making and leadership
- Team growth and evolution
- Technical and multidisciplinary teaming

3.4 COLLABORATION AND CHANGE
- Establishing diverse connections and networking
- Appreciating different roles, perspectives and interests
- Negotiation and conflict resolution
- Advocacy
- Bringing about intentional change

4. LEADING THE INNOVATION PROCESS

UNESCO PILLAR: LEARNING TO DO

4.1 MAKING SENSE OF GLOBAL SOCIETAL, ENVIRONMENTAL AND BUSINESS CONTEXT
- Appreciating the potential and limitations of science and technology, their role in society and society's role in their evolution
- Taking responsibility for sustainable development, including social, economic, environmental and work environment aspects
- Understanding the technical products, systems and infrastructure of the sector
- Understanding the enterprise – culture, stakeholders, strategy and goals
- Understanding the business context – markets, policy and ecosystem of the sector

4.2 VISIONING – INVENTING NEW TECHNOLOGIES THROUGH RESEARCH
- The research process – hypothesis, evidence and defense
- Basic research leading to new scientific discovery
- Research aimed at developing new technologies
- Imagining utility of new science and technology
- Developing concepts and reducing to practice

4.3 VISIONING – CONCEIVING AND DESIGNING SUSTAINABLE SYSTEMS
- Identifying stakeholders need and wants
- Identifying and formulating objectives and goals
- Conceiving and architecting products and services around new technologies and identifying their impact
- Disciplinary and multidisciplinary design for sustainability, safety, aesthetics, operability and other objectives
- Understanding the technical context and ecosystem of the product or service
- Design process management, including planning, project judgment and effective decision-making

4.4 DELIVERING ON THE VISION – IMPLEMENTING AND OPERATING
- Designing and optimizing sustainable and safe implementation and operations
- Manufacturing and supply chain operations
- Supporting the system life cycle including evolution and disposal
- Implementation and operations management

4.5 DELIVERING ON THE VISION – ENTREPRENEURSHIP AND ENTERPRISE
- New venture conceptualization and creation
- Financing product development and new ventures
- Building and leading an organization and extended organization
- Initiating engineering and development processes
- Selling, marketing and distributing products and services
- Understanding the value chain – the innovation system, networks and infrastructure
- Managing intellectual property and respecting the legal process