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Aiming for 21st. Century Skills

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Introduction
There is a saying, “In education everything happens 50 years later”. If true, this may have been not too problematic in older times, when changes were slow, but in times like ours where changes are extremely fast, it will be disastrous. Instead of being behind, education should be ahead. Primary-school, for instance, will have to prepare today’s students for their entrance in society, which will be about twenty years from now. However, this is not the case. Instead, Tony Wagner (2008) speaks of an “achievement gap” between what schools (in the USA) are teaching and what students will need to succeed in today’s global knowledge economy. He argues that, “students are simply not learning the skills that matter most for the twenty-first century” (ibid, 8-9). And he goes on to say that, “Our system of public education—our curricula, teaching methods, and the tests we require students to take—were created in a different century for the needs of another era. They are hopelessly outdated.” (ibid, 8-9). If we focus on employability, we may observe, that future employees in countries such as the USA will have to compete with colleagues in other countries with similar skills who work for lower wages. But, more importantly, the skills that the current and future jobs require anywhere, differ significantly from what current education offers. Wagner interviewed numerous CEO’s of large companies and he found a strong communality in what they look for in new employees; as one of them phrases it: “First and foremost, I look for someone who asks good questions.” (ibid, 2). The underlying rationale is that these employees will have to function in dynamic organizations. Employees today continuously have to learn new things. From this perspective, asking the right questions, is an important skill. In this respect, there is, however, a huge gap between what society demands and what schools offer. Prevailing language educa-
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... aims at technical reading skills, but does not ask students to think about what they read. Mathematics instruction also often focuses on skills, instead of understanding. Schools, Wagner (ibid) goes on to say, are not designed to support students in learning to think. The reason for that, he argues, is that we as a society never asked schools to teach students to think. This is reflected in national tests that are not designed to assess the ability to reason and analyze. The point is, the world has changed, schools have not.

Next to the dynamics of the modern workplace, there is also a shift in the type of work people do. Empirical research by the economists Levy and Murnane (2006) shows that employment involving cognitive and manual routine tasks in the USA dropped between 1960 and 2000, while employment involving analytical and interactive non-routine tasks has grown in the same period. This change especially concerned industries that rapidly automatized their production. Parallel to the development in industry, similar changes occurred in other areas where a strong computerization took place. This change happened on all levels of education. Jobs with a high routine character are disappearing. Jobs that will be offering good prospects for the future, are jobs which concern non-routine tasks, which are tasks that require flexibility, creativity, problem solving skills, and complex communication skills. Autor, Levy, and Murnane (2003) refer to examples such as reacting to irregularities, improving a production process, or managing people. The jobs of the future are the ones that ask for flexibility, creativity, lifelong learning, and social skills. The latter are jobs that require communication skills, or face-to-face interaction—such as selling cars or managing people. These changes do not only affect the decline or rise specific jobs; existing jobs are changing as well. Secretaries, and bank employees for instance have got more complex tasks since word processors and ATM’s have taken over the more simple tasks.

Earlier, Friedman (2005) pointed to the fact that the effects of computerization and globalization overlap and reinforce each other. Routine tasks can easily be outsourced, since information technology enables a quick and easy worldwide exchange of information. The latter also makes it possible to outsource business services, such as call-centers, or the work of accountants and computer programmers. Another effect of globalization is that it forces companies to work as efficient as possible. This requires companies to immediately implement computerization and outsourcing when it is economically profitable and strengthens the market position of the company. It also demands of the company to be on the lookout for opportunities to im-
prove efficiency. As a consequence, working processes will have to be adapted continuously. This in turn, puts high demands on the workers, who have to have a certain level of general and mathematical literacy to be able to keep up.

In summary we may conclude that schools will have to change to comply with the requirements imposed by our rapidly changing society. In this paper we will especially look into the consequences for mathematics education. We will start by taking a closer look at the 21st century skills. This will reveal the need for changes in the nature of the instructional process, and we will discuss what this means for mathematics education by reviewing the main characteristics of, annex requirements for, problem-centered, interactive, mathematics education. Next we will turn to the content of mathematics education, which also has to change. Will we start with the 21st century skills.

**21st century skills.**

Voogt & Pareja Roblin (2010), who reviewed the literature around five theoretical frameworks on 21st century skills, observe that the need for 21st century skills is mostly addressed by private or business initiatives, while educational leaders, practitioners and the educational community do not actively participate in the debate. The frameworks they reviewed concern: the ‘Partnership for 21st century skills’ (Partnership for 21st century skills, 2008), ‘EnGauge’ (North Central Regional Educational Laboratory and the Metiri Group, 2003), ‘Assessment and Teaching of 21st Century Skills’ (ATCS) (Binkley, Erstad, Herman, Raizen, Ripley & Rumble (2010), ‘National Educational Technology Standards’ (NETS) (Roblyer, 2000), and ‘Technological Literacy for the 2012 National Assessment of Educational Progress’ (NAEP). Dede (2009) compares similar frameworks in his review of 21st century skills. Both review studies show that the frameworks appear to strongly agree on the need for skills in the areas of communication, collaboration, ICT literacy, and social/cultural awareness. We may take Wagner’s (2008) list of what he calls, ‘the new survival skills’, as exemplary:

1. critical thinking and problem solving
2. collaborating and leading by influence
3. agility and adaptability
4. initiative and entrepreneurism
5. effective oral and written communication
6. accessing and analyzing information
7. curiosity and imagination.
We may also follow Wagner (ibid) in arguing that the 21st century skills are not just about employability. They will also have to include broader goals, such as becoming a responsible, active and well-informed citizen. Wagner (ibid) typifies this broader goal by asking if the students would eventually be well-equipped for acting as a member of a jury within the US legal system: “Would they know how to distinguish fact from opinion, weigh evidence, listen with both head and heart, wrestle with the sometimes conflicting principles of justice and mercy, and work to seek the truth with their fellow jurors?” (Wagner, 2008, xvi-xvii). This characterization resonates with the theme of this conference: “Democracy in mathematics curriculum”, and the corresponding issue of contributing to critical thinking and decision-making in the society. This begs the question of how to translate these lofty goals into instructional practice.

**Mathematics education for 21st. century skills**

Most publications on 21st century skills do not discuss how these goals might be achieved in education. It seems fair to say, however, that adopting 21st. century skills as educational goals will primarily affect the way instructional practice is shaped. Mathematics education seems to be a good place to incorporate these goals. Dam, & Volman (2004), for instance, conclude on basis of a review study that critical thinking is best developed in conjunction with science and mathematics education. But also in a more general sense, it may be argued that interactive, problem-centered, mathematics education will contribute to most 21st. century skills. However, if we want to integrate the objective of fostering 21st. century skills with attaining the regular goals of mathematics education, we will have to find a way by which problem solving, collaborating, communicating etc. serves the mathematics goals. In theory this is not too problematic, since the literature on reform mathematics points to this very type of activities—problem solving, collaborating, communicating etc.—as necessary conditions to enable students to construct meaningful mathematics. “In theory”, because we know that creating mathematics classrooms which can be characterized as interactive and problem-centered is not easy. We will discuss this issue by reviewing the main characteristics of, annex requirements for, problem-centered, interactive, mathematics education.

**Local instruction theories**

By reform mathematics we mean an approach to mathematics education that assumes that students have to construct or reconstruct mathematics by
themselves with help of the teacher and the textbook. Instead of reconstructing, one may also speak of reinventing—following the tradition of realistic mathematics education (RME) (Gravemeijer, 2008). One of the prerequisites for fostering reinvention—which has been a focus of RME research—is the availability of local instruction theories that serve the need for guidelines about the routes along which students might reinvent pieces of mathematics. A local instruction theory consists of a theory about a possible learning process for a given topic, and the means of supporting that process. Mark that a local instruction theory should not be confused with a scripted textbook. The local instruction theory is meant to function as a framework of reference for teachers.

**Hypothetical learning trajectories**

On the basis of such a framework of reference a teacher may design so-called ‘hypothetical learning trajectories’ (Simon, 1995) for the actual instructional activities in his or her classroom at a given moment in time. With the term hypothetical learning trajectory, Simon (1995) refers to the notion that a teacher has to deliberate on what mental activities the students might engage in as they participate in the instructional activities, he or she is considering. A decisive criterion of choice then will be how those mental activities relate to the chosen learning goals. He emphasizes the hypothetical character of those learning trajectories; the teachers are to analyze the reactions of the students in light of the stipulated learning trajectory to find out in how far the actual learning trajectory corresponds with what was envisioned. Based on this information the teacher has to construe new or adapted instructional activities in connection with a revised learning trajectory.

**Classroom social norms**

In addition to a sound planning of the instructional activities, another prerequisite for inquiry mathematics concerns the participation of the students. For the point is that students do not easily engage in problem solving and reasoning in regular classrooms (Desforges & Cockburn, 1987). Cobb & Yackel (1996) argue that this is not surprising, because students are often familiar with a classroom culture in which the classroom social norms (Cobb & Yackel, 1996) are that the teacher has the right answers, that the students are expected to follow given procedures, and that correct answers are more important than one’s own reasoning. In this type of classrooms teachers usually ask questions of which they already know the answer. Apart from being used to this situation, students have learned what to expect
and what is expected from them. In relation to this, Brousseau (1988) speaks of an implicit ‘didactical contract’. Significant, however, is that the students have learned this by experience, not because the teacher told them so.

In contrast to what is common in school mathematics, the classroom has to work as a research, annex learning, community. To make this happen, the students have to adopt classroom social norms that fit an inquiry-oriented classroom culture. These encompass, the obligation to explain and justify one’s solutions, to try and understand other students’ reasoning, and to ask questions if one does not understand, and challenge arguments one does not agree with. In addition to those social norms, Cobb & Yackel (1996) observe that the teacher also has to establish socio-mathematical norms, which relate to what mathematics is. This is expressed in norms about issues such as, what counts as a mathematical problem, what counts as a mathematical solution, and what counts as a more sophisticated solution. In regard to the latter, we may argue that socio-mathematical norms lay the basis for the intellectual autonomy of the students, as it enables them to decide for themselves on mathematical progress.

**Task orientation**

In addition to appropriating inquiry-based norms, students also have to be inclined to invest effort in solving mathematical problems, discussing solutions, and discussing the underlying ideas. Students may engage in learning activities for different reasons. The attitude of students in a mathematics classroom can be broadly divided in two categories, ego orientation and task orientation (Jagacinski & Nicholls, 1984). Ego orientation implies that the student is very conscious of the way he or she might be perceived by others. Ego-oriented students are afraid to fail, or to look stupid in the eyes of their fellow students, or the teacher. As a consequence, they may choose not to even try to solve a given problem, in order to avoid embarrassment. Task orientation on the other hand implies that the student’s concern is with the task itself, and on finding ways of solving that task. Research shows that task orientation and ego orientation can be influenced by teachers.

Cobb, Yackel & Wood (1989) report on a study on a socio-constructivist classroom, where task orientation was fostered. Part of their approach was to change the classroom culture from one of competition, where students compare themselves with each other, and with the criteria set by the teacher, into a classroom culture, where students would measure success by comparing their results with their own results earlier. We may think of the latter perspective as one similar to that of an amateur painter or amateur musician.
An amateur musician would not think of comparing him- or herself with others; there would always be many people performing better. Instead an amateur musician would be pleased if he or she would master a piece, which he/she could not play some time ago. A similar situation is possible in a mathematics classroom, where the goal for the students would be personal growth. Here, experiencing an ‘Aha-Erlebnis’, for instance, may function as an incentive. In such a classroom, students might even protest to be given ‘the solution’, for that would deprive them from the satisfaction of figuring out things for themselves. The aforementioned research of Cobb et al. (1989) shows that a classroom culture that emphases the exchange of ideas, and the development of mathematical understanding as a collaborative endeavor, may foster the task orientation of the students.

**Mathematical interest**

In connection with student motivation, we may add that next to the obvious “pragmatic interest”, which realistic problems appeal to, students will also have to develop “mathematical interest” (Gravemeijer & Van Eerde, 2009). This concerns the preparedness of the students to the investigate solution procedures, concepts and so on, from a pure mathematical perspective. This is a necessary condition for construing more sophisticated mathematics. Mathematical interest will rarely come naturally, but has to be cultivated by the teacher by asking questions such as: What is the general principle here? Why does this work? Does it always work? Can we describe it in a more precise manner? We may assume that the teacher can foster the students’ mathematical interest by making mathematical questions a topic of conversation, and by showing a genuine interest in the students’ mathematical reasoning.

**Framing topics for discussion**

Another essential role of the teacher concerns the orchestration of productive whole-class discussions. For this the teacher has to identify the differences in mathematical understanding which underlie the variation in student responses (Cobb, 1997). Next, he or she has to frame these underlying mathematical issues as topics for whole-class discussions. And finally, he or she has to orchestrate a productive whole-class discussion on those topic in order to foster higher levels of understanding.

In a similar feign, Stein, Engle, Smith, & Hughes (2008), espouse five practices for promoting productive disciplinary engagement: anticipating students’ mathematical responses, monitoring student responses, purpose-
fully selecting student responses for public display, purposefully sequencing student responses, and connecting students responses. The first two overlap to some extent with Simon’s hypothetical learning trajectory, whereas the last three are related to identifying, framing, and discussing mathematical issues. Although a difference may be that Stein et al. (2008) seem to try to address both mathematical ideas and the solution strategies of the students, while Cobb (1997) emphasizes the mathematical issues that underlie student solutions, and tries to steer away from a focus on solution strategies as such.

**21st Century mathematical skills**

The publications on 21st century skills mostly list general skills. Elaborations of what changes are needed in the content of the various topics that are taught, are very scarce. With some exceptions, there is also little attention is given to the content of the mathematics curriculum. One of the reasons may be that one of the effects of computerization is that mathematics becomes invisible. Mathematics is hidden in integrated systems, such as spreadsheets, automatics cashiers, and automated production lines. However, a consequence of this is that many people become “mathematics consumers”, as Levy en Murnane (2006, 19) put it. They argue that people who use computerized systems are expected to make decisions on the basis of the output of hidden mathematical calculations. The computerized equipment does the actual calculation. However, they go on to say, if the decision maker does not understand the underlying mathematics, he or she is very vulnerable to serious errors of judgment. If we follow this line of reasoning, we may discern two seemingly conflicting tendencies. On the one hand, we appear to need less and less mathematics, since various apparatus take over a growing number of mathematical tasks. On the other hand, we will need more mathematics as we develop into ‘mathematics consumers’, who become increasingly dependent of the quantitative information and mathematical models—which we ought to understand.

The aforementioned hidden character of mathematics in the information society makes it difficult to establish, what mathematics students will have to learn to become sensible mathematics consumers. To answer this question, we will follow two tracks. The first concerns research of mathematics at the workplace, the second concerns an analysis of the role of computers as interface between the physical world and the computer user.
Techno-mathematical literacy's

When trying to relate the goals of mathematics education to the requirements of the workplace, a complication is that the mathematics that is used at the workplace is strikingly different from conventional mathematics (Hoyles & Noss, 2003; Roth, 2005). To describe this specific kind of mathematics, Hoyles and Noss (2003) coined the term “techno-mathematical literacy’s”—or TmL’s for short. TmL’s are defined as idiosyncratic forms of mathematics that are shaped by workplace practices, tasks, and tools. Acting successfully at the workplace is dependent on a combination of mathematical knowledge and contextual knowledge.

In a recapitulatory report, Hoyles, Noss, Kent & Bakker (2010) mention as one of their key findings, that artifacts comprising symbolic information in the form of numbers, tables and graphs are often understood as “pseudo mathematics”. This means that these representations are conceived as labels or pictures, without an understanding of the underlying mathematics. They argue that, “Symbolic information thus failed to fulfill its intended role in facilitating communication across ‘boundaries’ between communities within and beyond the workplace” (ibid, 196). Important mathematical skills that come to the fore in their research are: reading tables and graphs, identifying and measuring key variables, reasoning about models in terms of the key relationships between variables, and representing and interpreting data.

We may further note that the role of TmL’s does not simply boil down to applying mathematical knowledge. Students will have to be able to flexibly adapt their existing mathematical knowledge or adopt new knowledge. This asks for experience with a variety of non-canonical forms of mathematics.

Quantitative models of reality

Apart from studying mathematics at the workplace, we may trace mathematical skills that are needed in a computerized environment, by analyzing the role computers and computerized appliances play as interfaces between the users and the concrete reality. In relation to this, we may discern the following processes:

- reality is quantified to make it accessible for computers—as computers only work with numbers;
- these numbers are processed by the computer on basis of models that describe interdependencies between variables;
- the output, which often has some mathematical form, is interpreted.

Thus in order to understand how a computer deals with reality, one must,

- have some idea of what quantifying (or measuring) entails;
- understand at some level, what a variable is, how we can reason about interdependencies between variables, and how computer models represent reality;
- has to be able to interpret the output of computers.

An important aspect of a measuring is that there will always be some inaccuracy and uncertainty involved. In general students do not realize that there will always be some measurement error, or that a repeated measurement may result in a different outcome. Nor do they realize that variance is part of industrial production, even though they will be aware of the phenomenon of natural variance in nature. We would argue that it is important for students to develop this kind of understanding, for many of the numbers they will have to work with will be the result of sampling. We may further follow Jones (1971) in his observation that measuring an object comprises assigning a value to a variable; what is measured is not the object but a property of that object. The significance of this observation comes to the fore when we look at co-variation. In such cases we do not compare the individual lengths and weights of certain persons, but we study how “length” varies with “weight”.

Fortunately information technology offers eminent possibilities for creating educational tools for helping students to come to grips with these ideas. Hoyles et al. (2010), for instance, report on the use of interactive computer tools that present symbolic information such as graphs, models expressed in algebraic symbols, or numerical measures. Experiments with such computer tools (which they call, technology-enhanced boundary objects) show that they can be employed successfully in enhancing the meanings of the symbolic information by making them more visible and manipulable, and therefore more accessible. We may note that this use of computer tools is in line with Kaput’s, faith in the educational potential of information technology that allows for the use of dynamic representations (Kaput & Schorr, 2007). Computers can show the numerical results or graphical representations of measuring activities real time on a screen, but also offer representations of simulations that can be manipulated at will.

We may mention two examples of the educational use of dynamic representations in service of the mathematical objectives mentioned above. One concerns a simulation of a train on a rail track, which is accompanied by a graphical representation of the speed of the train, which can be used to foster an understanding of co-variation and informal calculus (Galen & Gravemeijer, 2010). A second example concerns an introduction to explora-
tory data analyses with the help of so-called computer minitools (Gravemeijer & Cobb, 2006), that allow for a variety of representations and ways of structuring of data sets. While analyzing data with the help of these minitools, students may develop a qualitative notion of a distribution of data as an object with certain characteristics, such as shape and spread.

Conclusion

We started by observing that there is a significant gap between what students learn at school and what modern society demands. Computerization and globalization result in a change in job requirements that involves a shift from routine tasks towards non-routine tasks. The jobs of the future require flexibility, creativity, problem solving, life-long learning and complex communication skills. Our fast changing information society not only put new demands on workers, it also affects our roles as learners and citizens. In relation to this, we referred to Wagner’s (2008) benchmark that the students eventually would have to become well-equipped for acting as a member of a jury in the US legal system.

Similar to Wagner, many publications in this area use the term, “21st century skills”; skills that may be summarized as flexibility, critical thinking, problem solving, collaborating, and communicating. We argued that these skills fit very well with problem-centered, interactive, mathematics education, and we reviewed the most important characteristics of this type of mathematics education.

We further discussed what changes in the content of mathematics education would be needed. Both research on mathematics in the workplace, and an analysis of the role of computers as interface between the physical reality and the user, point to topics such as, measuring, tables, graphs, variables, models of relationships between variables, and elementary statistics.

Finally we indicated how computer tools may help students in coming to grips with the aforementioned mathematics, by offering dynamic representations. In conclusion, we want to stress the urgency of a reconsideration of the goals of mathematics education in light of the demands of the 21st century, and the need to start experimenting with educational practices that may foster these goals.

Notes
1. Mark that most publications on 21st century skills stem from Western countries, which implies a certain bias. We may argue, however, that the 21st century skills that are identified will be or become significant for other countries as well.

References


