

Personalized Integrated Educational System: Technology Functions for the Learner-Centered Paradigm of Education

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Abstract

The learner-centered paradigm of instruction differs in such fundamental ways from the teacher-centered paradigm that it requires technology to serve very different functions. In 2006, a research team at Indiana University began to work on identifying those functions and published their results in 2008. Subsequently, the team elaborated and refined those functional specifications, which are described herein as the Personalized Integrated Educational System (PIES), a technology system that has not yet been developed to support learner-centered education. The four major

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functions are **recordkeeping** for student learning, **planning** for student learning, **instruction** for student learning, and **assessment** for and of student learning. Secondary functions include **communication and collaboration**, **PIES administration**, and **improvement** of PIES. Each of these functions is described in detail, followed by specifications for the system architecture, including **interoperability**, **modularity**, and **customizability**.

Keywords

intelligent tutoring systems, interactive learning environments, interdisciplinary projects, multimedia or hypermedia systems, pedagogical issues

Much has been written about the need for changing the paradigm of education from the sorting-focused, industrial-age, factory model of schools to the learning-focused, information-age, learner-centered paradigm, and there is growing evidence that paradigm change is the only way to significantly improve educational systems for a postindustrial society (Banathy, 1991; Bransford, Brown, & Cocking, 2000; Branson, 1987; Bush & Mott, 2009; Caine & Caine, 1997; Christensen, Horn, & Johnson, 2008; Covington, 1996; Darling-Hammond, 1990, 2002; Education Commission of the States, 1996; Fullan, 1993, 1999, 2003; Lieberman, 1995; McCombs, 2013; McCombs & Whisler, 1997; National Commission of Excellence in Education, 1983; National Education Commission on Time and Learning, 1994; Office of Technology Assessment, 1995; Perkins, 1992; Reigeluth & Garfinkle, 1994; Reigeluth & Karnopp, 2013; Sarason, 1990; Schlechty, 2001, 2005; Senge, 2000; Sizer, 1985; Toffler, 1980, 1990; Wagner, 1994, 2002; W. Watson, S. Watson, & Reigeluth, 2013; Yonezawa, McClure, & Jones, 2012).

The learner-centered paradigm marks the following shifts:

- From time-based student progress to competency-based student progress,
- From norm-referenced tests to criterion-referenced tests,
- From standardization to personalization,
- From teacher as sage on the stage to teacher as guide on the side,
- From decontextualized content in the disciplines to authentic interdisciplinary projects,
- From students as passive and teacher-directed to students as active and self-directed learners,
- From teacher planning to a personal learning plan for every student,
- And much more (Reigeluth & Karnopp, 2013).

However, for the learner-centered paradigm to work well and cost-effectively, powerful technological tools are crucial for several reasons (McCombs & Vakili, 2005; Reigeluth & Karnopp, 2013). First, they save huge amounts of teacher

time, making it possible and cost-effective for teachers to provide truly personalized, attainment-based instruction and assessment. Second, they afford immersive project environments that enhance student motivation. Third, they provide infinitely patient and soundly designed tutorials at the moment a student needs them. This article offers suggestions for many of the functions that such tools need to serve.

In 2006, a research team at Indiana University began to work on identifying the functions that technology should serve to support the learner-centered paradigm of education. This resulted in several research studies (An & Reigeluth, 2011; Aslan, 2012; Aslan, Huh, Lee, & Reigeluth, 2011; Dutta, 2013; Yildirim, Reigeluth, Kwon, Kageto, & Shao, 2013) and a set of design specifications for an integrated technology system (Reigeluth, S. Watson, W. Watson, Dutta, Chen, & Powell, 2008), which was subsequently called the Personalized Integrated Educational System (PIES) (Reigeluth, 2014; W. Watson, S. Watson, & Reigeluth, 2012), because it is designed specifically for personalized instruction, and it requires seamless integration of the full range of functions needed to support student learning. As the team continued this work and learned more from our research, we saw the need for significant enhancements to those initial specifications.

One way to think about PIES is in terms of:

- functions to support teachers,
- functions to support administrators,
- functions to support parents, and
- functions to support students.

Clearly, there is overlap among these functions, but in this article, we focus on functions to support students, which is most important in the learner-centered paradigm of education.

We still see four major functions and several secondary functions to support students, all of which should be seamlessly integrated into a single, open-architecture system. The major functions include the following:

- **recordkeeping** for student learning,
- **planning** for student learning,
- **instruction** for student learning, and
- **assessment** for (and of) student learning.

The secondary functions include **communication and collaboration**, **PIES administration**, and **improvement** of PIES. The major changes to PIES from the previous version are shown in Table 1. In this article, each of PIES' major and secondary functions is discussed, followed by a description of the architecture for PIES. Figure 1 shows an information schematic of this proposed technology system.

Table 1. Major Changes From the Previous Version of PIES.

Function	Subfunction	Major changes
Recordkeeping	Standards inventory	<ul style="list-style-type: none"> • Clarifies that standards are broken down to individual competencies or other attainments. • Adds Prensky's new paradigm of curriculum.
	Personal attainments inventory	<ul style="list-style-type: none"> • Degrees of mastery are addressed. • Student ownership of the inventory is affirmed (portability). • Individual and team products are shareable.
	Personal characteristics	<ul style="list-style-type: none"> • No changes.
Planning	School- and group-level planning	<ul style="list-style-type: none"> • Adds two levels of planning beyond the individual level: the school level (annual theme, plays, fairs, exhibits) and the advisory group level (culture, teachable moments, life problems).
	Long-term goals	<ul style="list-style-type: none"> • Clarifies connection with the personal characteristics inventory, along with suggestions for instrumental attainments and other supports.
	Prospective attainments	<ul style="list-style-type: none"> • Changes the name from "current options" for greater clarity.
	Short-term goals	<ul style="list-style-type: none"> • Adds the rationale for project periods, along with ways the rate of student learning is made flexible within project periods of a fixed length.
	Projects	<ul style="list-style-type: none"> • Now helps students to design their own projects or activities, as an alternative to help in selecting them. • Helps an advisory committee to modify a selected project. • Helps an advisory committee decide if a project will be done solo, collaboratively in same role, or cooperatively in different roles, and selection of the student's role. • Describes the project bank (database), along with metadata, service-learning projects, and exemplary artifacts.
	Teams	<ul style="list-style-type: none"> • No changes.
	Supporting roles	<ul style="list-style-type: none"> • Identifies additional nonteammates who may help the student learn.
	Contracts	<ul style="list-style-type: none"> • Adds the student level (a second level of contracts) to the project or activity level.

(continued)

Table 1. Continued

Function	Subfunction	Major changes
Instruction	Projects	<ul style="list-style-type: none"> • Specifies the contents of a project or activity contract in greater detail. • Allows for modifications to a contract. • Specifies connection with a project-management subfunction.
	Scaffolding	<ul style="list-style-type: none"> • Provides more details about the projects subfunction, especially for student-designed projects. • Adds provision of a virtual project environment (simulation or virtual world) with a virtual coach. • For real-world project environments, adds project elements and tools, as well as a virtual coach. • Specifically mentions subfunctions for student collaboration, production, presentation, and reflection. • Adds a subfunction to help students find, evaluate, organize, and store information and resources. • Adds a subfunction to help resolve team conflicts. • Expands on instruction to include coaching. • Describes ways instruction is triggered. • Expands on how the instruction is personalized. • Describes how PIES fosters learning metacognitive skills, curiosity, creativity, character development, and more. • Describes access to PIES anywhere, anytime, with any device. • Describes access to OERs.
Assessment	Integrated performance	<ul style="list-style-type: none"> • Adds a second level of assessment beyond the individual—the team—which is assessed in the project environment. • Adds team self-reflection, peer evaluation, and expert evaluation as assessment tools.
	Individual learning	<ul style="list-style-type: none"> • Adds digital badges or certificates.

(continued)

Table 1. Continued

Function	Subfunction	Major changes
Secondary functions	Communication and collaboration	<ul style="list-style-type: none"> • No notable changes.
	PIES administration	<ul style="list-style-type: none"> • Reorganizes access, general student data, and personnel data into this category. • No other notable changes were made.
	Improvement of PIES	<ul style="list-style-type: none"> • Adds capability for PIES to evaluate and improve all its functions and add new ones as needed. Subfunctions for developing and improving instruction and assessments were moved here and elaborated a bit. • Adds capability for users to customize their portals.
System architecture	New section	<ul style="list-style-type: none"> • Describes such features as cloud-based, five databases, interoperability, modularity, and customizability.

Note. PIES = Personalized Integrated Educational System; OER = open educational resource.

Recordkeeping for Student Learning

Competency-based student progress is not possible without keeping track of what each student has learned. Report cards or transcripts serve a parallel function in the sorting-focused, industrial-age paradigm of education, except that these do not tell you specifically what each student has learned, only how well the student has done compared with other students in the class. The **recordkeeping** function of PIES replaces report cards and provides detailed information about student learning. PIES keeps three types of records: (a) a **standards inventory** that includes all the attainments that students must or could achieve, including academic and nonacademic ones, (b) a **personal attainments inventory** that includes all those attainments that each student has already achieved, along with useful learning analytics for each attainment, and (c) a **personal characteristics inventory** that contains each student's personal characteristics that are pertinent to student learning.

Standards Inventory

The **standards inventory** keeps a list of all required and optional academic and nonacademic standards, offered by any source—national, state, local, and

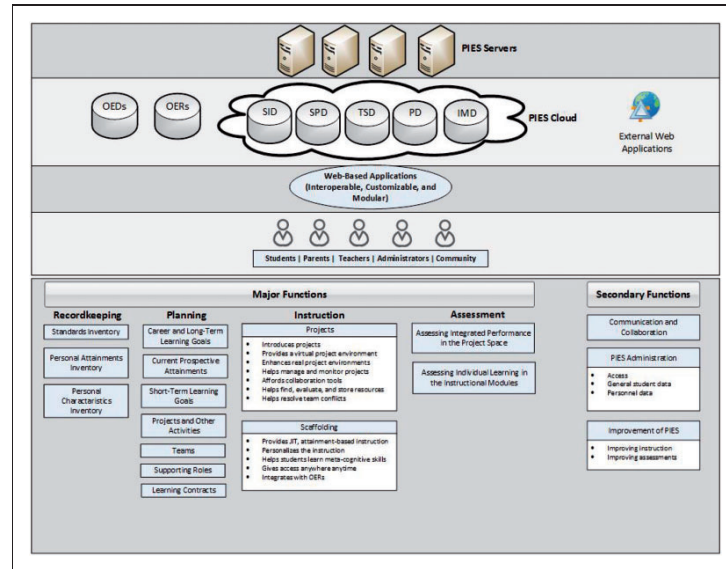


Figure 1. PIES information schematic.

OED = open educational database; OER = open educational resource; SID = Standards Inventory Database; SPD = Student Profiles Database; TSD = Teammate Selection Database; PD = Projects Database; IMD = Instructional Modules Database; PIES = Personalized Integrated Educational System.

personal. The standards are broken down in a hierarchical manner to individual attainments such as skills, understandings, dispositions, and so on. The **standards inventory** displays the attainments in a customizable domain map or chart format based on domain theory (Bunderson, Wiley, & McBride, 2009). Each domain map includes (a) major attainments with boundaries showing the easiest and hardest version of each attainment, (b) categories of attainments, where each category represents a pathway for learning, and (c) a difficulty-based sequence of attainments along each pathway. For each attainment in the map, there is an indication as to whether it is a required standard, and if so, what level of difficulty is required. This map enables the learner to navigate through the attainments within each subject domain such that when the learner masters one attainment, the map indicates the more advanced attainments that are now within reach—Vygotsky’s (1978) “zone of proximal development” (see Planning for Student Learning section).

The **standards inventory** includes such currently optional standards as social, emotional, and character development (Goleman, 1995, 1998; Lewis, Watson, & Schaps, 1999; Lickona, 1991). Examples of a wide range of educational standards are offered by the Partnership for 21st Century Skills (n.d.), the International Society for Technology in Education (2007), the U.S. Department of Labor (1991), the Common Core (<http://www.corestandards.org>), and individuals like Daniel Goleman (1995, 1998) and Thomas Lickona (1991). However, most of these standards need to be further broken down into individual attainments. Prensky (2014) has proposed organizing standards around the four key pillars of thinking effectively, acting effectively, relating effectively, and accomplishing effectively rather than the current four pillars of math, language arts, science, and social studies. This represents a truly different and very promising paradigm of curriculum.

Teachers and other experts who are involved in student learning can customize the **standards inventory** based on student needs such as learning gaps and cross-disciplinary understanding (Dutta, 2013). In essence, the standards inventory presents a list of things that should or can be learned, along with levels, standards, and criteria at which they should or could be learned.

Personal Attainments Inventory

This inventory supports student learning by keeping track of each student's progress on attainments. Portions of the domain map in the **standards inventory** are displayed in each student's **personal attainments inventory**. The student's progress is indicated, for example, by an attainment in the map automatically turning a darker and darker shade from when a student starts working on it, to when he or she masters it, along with date and time mastered and access to learning analytics that provide the complete history of his or her work on it, as in the Khan Academy. This way, all the authorized stakeholders (i.e., student, teachers, and parents) can easily see how the student is doing and offer support when needed.

Also, a community may want all children to be able to do certain things by a certain age, especially for basic skills, to make sure that students are not overlooking foundational skills and knowledge. Thus, it may be important to foster some well-rounded development, rather than letting a student exclusively study things that he or she wants when he or she wants, so the **personal attainments inventory** can also report the student's attainments compared with target ages (if any) for mastery of required standards (adjusted automatically by the student's average speed of learning, which is continuously tracked by PIES over time).

Each attainment, or set of related attainments, is linked to a repository of evidence of its mastery in the form of summary data or original artifacts that are automatically tagged according to the learning goals (Garrett, Thoms, Alrushedat, & Ryan, 2009). Tags help students easily organize and find their

artifacts and allow the student to easily pull out selected artifacts into different e-portfolios for different purposes (exportability). Students can choose to make parts of their evidence visible to selected others or the public in general. Project and module developers can link to the evidence (with student permission) to showcase their instructional modules. Furthermore, the **personal attainments inventory** belongs to the student, not the school system, so the student can use it throughout his or her life as a tool for lifelong learning.

In addition, a sharing feature is provided in the **personal attainments inventory**. An individual student or a team can set a final artifact or a video of their performance for public display, in which case it is publicly posted and searchable by the school community. The student or teacher uses a tagging function so the audience can navigate easily to the most appropriate products. When made public, the product can also be linked to the project in the project bank (see Instruction for Student Learning section) as a legacy (Schwartz, Lin, Brophy, & Bransford, 1999) for future students to access, either locally or broadly.

Lastly, for all the records of these personal attainments, the student can flexibly control access and levels of security. For example, while a student, his or her teachers, and his or her parents have full access to the records, the student could give potential employers or community members limited or no access.

Personal Characteristics Inventory

The **personal characteristics inventory** keeps record of each student's personal characteristics that are useful for promoting student learning. These characteristics are different from general student data, such as address, birthdate, and information about parents or guardians. Personal characteristics include learning styles, profile of multiple intelligences, special needs, major life events, career goals and interests, and so forth. Personal characteristics are continuously updated through surveys and automatic collection of data from the **instruction** and **assessment** functions of PIES about which instructional methods work well for each student.

Personal characteristics are useful for (a) decisions about learning goals and objectives, (b) teacher coaching and advising for the student, and (c) customization of PIES' tutorials, simulations, and even projects.

The student owns and can flexibly control access to this inventory for security and privacy reasons. Level of access is typically granted depending on the relationship with the student. For example, parents or legal guardians, teachers, and students themselves are usually granted full access. However, students may give limited or no access to community mentors and other teachers and administrators.

Clearly, a customized paradigm of education requires keeping a lot of records. PIES greatly alleviates the time, drudgery, and expense of maintaining and

accessing those records. It helps ensure that appropriate standards are being met while customized attainments are achieved by each student.

Planning for Student Learning

Planning is one of the most important components of the learning process. “By engaging in preparation and planning in relation to a learning goal, students are thinking about what they need or want to accomplish and how they intend to go about accomplishing it” (N. J. Anderson, 2002, p. 3). While planning was one of the major responsibilities of teachers in the industrial-age paradigm of education, the learner-centered paradigm requires students and even parents to be actively involved in the planning process with guidance from the teacher.

Planning for student learning in the new paradigm needs to take place on three different levels: school, learning group (traditionally called a classroom or homeroom), and individual student. At the *school level*, many schools want to have an annual school theme that is consistent with the overarching philosophy, mission, and vision of the school. All planning activities can then be informed by overarching school-wide academic and social themes (Dutta, 2013). For example, the Project School in Bloomington, IN, chose “power” as its theme one year, addressing such questions as what power is, how it moves, what it looks like from different perspectives, how it keeps things the same, and so forth. PIES’ **planning** function helps all the teachers in a school to select and use an appropriate and powerful theme. It also helps for planning other aspects of school life, such as school plays, science fairs, art exhibits, and much more.

At the *advisory group level*, each mentor teacher¹ (often called a facilitator, guide, or advisor due to the radically different role) should plan ways in which all of that teacher’s students can learn together in a collaborative environment. PIES’ **planning** function helps each teacher decide on an appropriate culture or climate for the homeroom or workspace and ways to establish and maintain that culture, such as establishing ground rules collaboratively with the students and preparing in advance for the teacher to deal with typical events that may threaten that culture. The **planning** function also provides advice on how to recognize and take advantage of “teachable moments” that can address emotional, social, and character development issues. The function helps in diagnosing the causes of academic and social or emotional problems that arise and recommends alternative actions for dealing effectively with those problems. The function can use both keyword search and menu-driven decision tree to accomplish this.

At the *individual student level*, each student needs a personal learning plan that sets out learning goals and ways to meet them. The **planning** function helps each student’s advisory committee (the student, his or her parents, and mentor teacher) to collaboratively decide on career goals, long-term and short-term learning goals, projects, teams, supporting roles, and learning contracts.

Each of these subfunctions of individual student planning is described in detail in the following sections.

Career and Long-Term Learning Goals

Research by Schutz and Lanehart (1994) found that, “when long-term educational goals were accompanied by attempts at day-to-day educational sub-goals and useful learning strategies, high academic performance tended to occur” (p. 407). The **career and long-term learning goals** subfunction in PIES helps each student’s advisory committee collaboratively decide on long-term life goals and interests as well as career goals, which can be a powerful force in motivating the student to learn, even during early childhood.

First, the subfunction helps each student to explore career options. Questionnaires and existing information about the student’s interests and aptitudes are used to suggest careers that the student might want to explore. The student can then learn more about each of those careers through interactive video vignettes showing “a day in the life” of a person in that career. Because students typically change their life and career goals and interests often, the subfunction encourages each student to rethink or reaffirm his or her career goals on a regular basis. The student may also select more than one life or career goal if he or she has more than one area of interest.

Second, when the student selects an appropriate career goal, it is entered into the student’s **personal characteristics inventory** (along with all information about the student’s interests and aptitudes), as such information can improve instruction. The subfunction provides the student with information about the kinds of attainments one needs to achieve to succeed in that career, and those attainments are then listed as long-term learning goals. For older students, the subfunction provides information about potential community mentors² (e.g., a local engineer), grants, and scholarships to help them accomplish their long-term learning goals in pursuit of their career goals.

The **planning** function can generate annual or semiannual reports on the progress each student has made toward achieving his or her long-term goals. Goal setting is an important aspect of self-directed learning and consequently life-long learning (Zimmerman, 2002).

Current Prospective Attainments

Previously referred to as **current options** in the article by Reigeluth et al. (2008), **current prospective attainments** are the full range of required and optional standards (defined broadly as all kinds of learning and development) that are within reach for each individual student—ones that the student can learn without first learning other standards. PIES’ **planning** function does this by comparing a student’s **personal attainments inventory** (the student’s current attainments)

with the **standards inventory** (all required and optional attainments) to generate a comprehensive list or map of sets of attainments that the student could choose to work on next without overreaching. The student's advisory committee also has the option of adding, revising, or deleting attainments on the list. Based on the student's progress as measured by the assessment function (see Assessment for and of Student Learning section), the list is updated automatically by the system.

Short-Term Learning Goals

This subfunction helps the student's advisory committee to select, from the list of **current prospective attainments**, those attainments that the student will work on next, based on the students' long-term learning goals, interests, opportunities, requirements, parents' values, and so forth. These short-term learning goals include all dimensions of human development—social, emotional, physical or health, ethical, artistic, and psychological, as well as intellectual. For example, some short-term goals may be established for helping others through volunteer work in the community.

In the move away from time-based student progress, we envision that most school systems will establish project periods, for several reasons. First, it would be difficult for students to form different groups for new projects if there are not set dates for the beginning of projects. Second, in the real world, people need to meet project deadlines, so it is important to prepare students for that. Third, human nature is to not get things done until they are due, so having a deadline is a motivational issue. With project periods, rate of student learning is adjusted through selection of the *number* and *scope* of projects undertaken during a project period. Faster learners can undertake more projects and larger projects. Records of how many hours per week a project has taken, on average, are adjusted by PIES for each student's history of rate of learning, to help select an appropriate learning load for each student. The length of the project period is determined by the school but differs depending on the developmental level of the learners—at lower levels, project periods are shorter.

At the beginning of each project period, short-term goals are chosen by the student's advisory committee (mostly by the student with guidance from the rest of the committee).

Projects and Other Activities

Project-based learning is an important part of the learner-centered paradigm of education (McCombs, 2008; Reigeluth & Karnopp, 2013; United States Department of Education, 2010; Wolf, 2010), primarily because it can greatly enhance learner motivation and facilitate transfer of what is learned to the real world.

PIES' **planning** function helps a student to *select* or *design* projects or other activities (e.g., readings with discussions, or tutorials) to attain his or her short-term learning goals. For selection, it uses those goals to identify projects or other activities through which the student could attain those goals. It rank-orders those projects or activities on the basis of how many short-term goals each addresses; how well it aligns with the school's mission, vision, core principles, and current theme; and how well it aligns with the student's interests.

The student then selects (with input from his or her advisory committee) whatever combination of projects or activities he or she wants, based on customized weekly time estimates for each project. User ratings similar to those in Amazon also help the student to make good choices. After one project or activity is selected, PIES updates the rank-order of projects or activities for the remaining short-term goals, and the student selects additional projects or activities until the student's available time is filled.

Alternatively, if the student's advisory committee wants the student to design his or her own projects or other activities, the **planning** function helps him or her to design them based on his or her short-term learning goals; the school's mission, vision, core principles, and current theme; the student's interests, and current opportunities.

If a project is selected, the **planning** function allows the student (and his or her advisory committee) to customize and tailor project attributes, requirements, and assessment criteria to fully address his or her relevant short-term learning goals and interests. For example, it allows the committee to select such methods of assessment as products, reports, presentations, contests, single expert review, panel of experts, and public display of each project. The function helps the advisory committee decide whether a project will be done solo, or collaboratively with all teammates sharing the same role, or cooperatively with each teammate performing a different role. If the latter, the function suggests roles that are best aligned with the student's short-term goals and personal characteristics. The function also estimates the average number of hours per week to complete the project in the selected role given the length of the school's project period, and it adjusts that based on the student's speed of performance on prior projects.

The project "bank" or database on which the **planning** function draws is updated as new projects are posted by all advisory committees worldwide and even by local community members. Improvements to, or variations on, old projects can also be posted. Because service learning is a key tenet of the learner-centered paradigm (Billig, 2000; Reigeluth & Karnopp, 2013), the **planning** function allows community organizations and businesses to post upcoming projects to the local or regional section of the project bank.

The project bank also stores a variety of metadata for each project, such as the short-term learning goals (or attainments) that each project addresses,

assessment criteria and standards of performance, recommended methods of assessment (e.g., contests, single expert, panel of experts, public display), whether the project requires multiple roles, average number of hours required for each role, previous students' evaluations of the project, and previous students' products if they choose to make them public (through each school's repository, where the student and advisory committee can evaluate the products using a system similar to that used by Amazon customers to rate their purchases, and PIES can automatically generate a list of exemplary products). This also allows teachers to select exemplary artifacts to showcase student learning in their school.

For some short-term goals, such as learning about philosophy, a project may not be the most appropriate vehicle for meeting the goals. In such cases, PIES' **planning** function helps the advisory committee to plan other kinds of activities for meeting the goals.

Teams

Students may occasionally choose to do solo projects, though advisory committees ensure that their students engage in sufficient team projects to develop high levels of collaboration and conflict resolution skills. Literature suggests that when students are collaborating with peers on academic tasks, they show higher intellectual performance than when working alone (Bandura, 1986; Vygotsky, 1978). Bruner (1985) also stated that students enhance their problem-solving skills through cooperation, as they have more opportunities for interpreting given problems.

For team projects, the **planning** function identifies other students who are interested in doing the same project during the same project period, and if different roles are needed, it identifies students interested in each role. Then, the function helps the students select teammates who are in the same or even different schools. Teachers, schools, or even districts can add criteria to this selection process that ensure students don't only collaborate with their best friends—that they also team up with students of different gender, ability, compatibility, ethnicity, and socioeconomic status. PIES also uses personality inventories (e.g., Myers-Briggs) to help students understand why their teammates may behave quite differently and how to deal with that.

Supporting Roles

This subfunction in PIES helps the student's advisory committee to identify people—including themselves as well as other teachers, community or academic experts, senior students, parents, and guardians—to play supporting roles in helping the student learn from each project or other activity and helps them to define those roles.

Learning Contracts

“Learning contracts are practical devices helping one to bridge the gap between curricular requirements and self-initiated and self-directed learning” (Motschnig-Pitrik, Derntl, & Mangler, 2003). Each school or district establishes a project period appropriate for the developmental stage(s) of its students. Having the same start time makes it possible to form new teams for new projects. However, some projects span two project periods, and individual projects may span a fraction of a period. All local schools at the higher developmental levels typically coordinate the length and timing of project periods so that their students can collaborate with students from other schools.

As an essential part of the planning process, the **learning contracts** subfunction in PIES helps the advisory committee to develop learning contracts at two different levels: the student (or advisory committee) level and the project or activity level. At the student level, the contract specifies the short-term learning goals and all the projects or activities for a given project period. At the project or activity level, it is prepared and signed by all teammates and external collaborators (if any) and specifies the following for each project or activity: short-term learning goals, teammates (if any), student roles and responsibilities, mentor roles, roles of any external collaborators, deadlines, milestones, resources, assessment criteria, methods of assessment, and criteria for modifying the contract. Any modifications must be submitted through this function and be approved by the advisory committee. This **learning contracts** subfunction is linked with a subfunction that helps students and their advisory committees manage each project in the contract (see Provides a virtual project environment section).

Instruction for Student Learning

PIES’ **instruction** function contains subfunctions for **projects** and for **scaffolding**. It has a project database, a coaching database, and an instructional module database whose instructional modules are linked to specific points in projects when the instruction is needed just-in-time (JIT).

Projects

The **projects** subfunction (a) introduces projects to the student, (b) provides an authentic virtual environment within which to conduct the project or alternatively provides project elements that enhance real (community-based) project environments, (c) helps students organize and manage their projects (time and resources), and (d) helps teachers monitor the projects. It also (e) helps students collaborate with peers using various documentation and communication tools and (f) guides students to resolve conflicts that arise during teamwork.

Introduces projects. The **projects** subfunction introduces the project to students or helps teachers do so. Alternatively, it can help students initiate a project of their own design by helping them choose and use a checklist of considerations for initiating their project. Considerations include getting more information about the project, identifying tasks to perform with milestones for each, deciding who will do what and how they will work together, and identifying resources they will need. For predesigned projects, this is often done through a simulation or virtual world, such as Bransford's STAR LEGACY (Schwartz et al., 1999).

Provides a virtual project environment. In many cases, the subfunction provides a virtual world or simulation game in which the project is conducted. In such cases, it provides natural consequences for student actions within the virtual environment. A virtual environment is "a computer-generated display that allows or compels the user (or users) to have a sense of being present in an environment other than the one they are actually in, and to interact with that environment" (Schroeder, 1996, p. 25). Many researchers have argued that virtual environment and simulation can be used to facilitate learning tasks that lead to increased understanding, motivation, engagement, collaboration, and knowledge transfer (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005; Chittaro & Ranon, 2007; Dickey, 2005; Mennecke, Hassall, & Triplett, 2008; Rieber, 1992). When appropriate, the **projects** subfunction also provides virtual coaching as students proceed, with a virtual coach appearing JIT to offer advice (but not instruction—that is described in the next section).

Enhances real project environments. Real-world projects require students to solve authentic, hands-on, and interdisciplinary problems. In cases where a real-world environment is used for conducting the project, the subfunction can enhance that environment by introducing project elements related to the real environment, such as key knowledge, quality standards, planning, self-management, and other related resources. It can also provide tools for students to use while conducting the project, such as data collection, data analysis, communication, and collaboration tools. When appropriate, virtual coaching is also provided as students proceed. This helps connect their knowledge to the real world.

Helps manage and monitor projects. The **projects** subfunction helps students organize and manage their project work, including identifying, assigning, and monitoring tasks; managing time and resources; and documenting progress daily. Students log time they devote to each project each day to help their advisory committees keep track of their progress. This subfunction can also be used to organize and manage any nonproject activities. The **projects** subfunction helps teachers, parents, and other supporters monitor the projects and activities, by flagging ones that require guidance, facilitation, and scaffolding. Artificial intelligence is used, to provide expert guidance automatically, under the watchful eye

and additional insights of the teacher. The artificial intelligence can be deployed partly through pedagogical agent software. Hawryszkiewicz (2004) and Hawryszkiewicz and Lin (2003) detail the infrastructure for such agents to take on the role of teacher and expert and interact with learners by perceiving the progress of students in their learning activities and offering JIT assistance. The agents are also able to facilitate the learning process by helping students set up and manage their workspaces.

Affords collaboration tools. Various collaboration tools (such as documentation and communication tools) and social apps are used by students as collaborative and resource-sharing platforms. Social software and other tools like Google Drive, Skype, Redbooth, and Dropbox are integrated into the system, offering students personal tools for production, presentation, reflection, and collaboration. Networks are created among students, teachers, and experts working within the field to maximize learning. For example, social software tools like Weblogs and wikis can make student work visible to other students, allow students to follow each other's work, and give students access to each other's networks of people and references. These networks also allow teachers to follow and potentially participate in the work of students. This can be supported through connections between students' and teachers' Weblogs using RSS feeds and social bookmarking (Richardson, 2005).

Helps find, evaluate, and store resources. The **projects** subfunction helps students to find, evaluate, and store resources related to their project work and cultivate information literacy (American Library Association, 2000) to locate, evaluate, and use the needed information. It provides some guidance, demonstrations, and practice with feedback to develop good strategies for these activities. It teaches the concepts of personal knowledge management and how to retrieve, organize, and evaluate information from the web. One way this is done is to integrate open-source tools (such as social bookmarking tools, knowledge logs, and task managers) into the system as a mashup,³ with demonstrations on how these can be used for personal knowledge management (Weber, Thomas, & Ras, 2008).

Helps resolve team conflicts. The **projects** subfunction helps students and teachers address conflict resolution issues because conflicts are inevitable in teamwork, not just in school but also in family life and work life. Students learn conflict resolution strategies, which include "constructive self-management (emotional, cognitive, and behavioral self-control), communication, social perspective-taking, cooperative interpersonal problem solving, and promoting respect for individual and group differences" (Garrard & Lipsey, 2007, pp. 11–12). These strategies are learned as students who encounter problems may either use a decision tree or keyword entry within the PIES system, which then suggests particular strategies for dealing with the problem. This subfunction is available

to both students and teachers as a resource. When needed, students may contact their teachers for help so that teachers can direct students to specific strategies or offer personal suggestions for resolving conflicts.

Scaffolding

The **scaffolding** subfunction provides students with access to JIT personalized coaching and instruction anytime and anywhere as they work on their projects. According to Hmelo-Silver, Duncan, and Chin (2007), besides only offering direct instruction when students experience the need to learn something, scaffolding may also make parts of the task harder, to force students to engage with key disciplinary frameworks and strategies. These redirect students to examine counterclaims, articulate explanations, and reflect on progress. Coaching is provided JIT as needed, typically on student request, but occasionally on a predetermined schedule or suggestion by the student's virtual pedagogical agent. For the instruction, PIES uses validated instructional theory to help students develop specific skills, understandings, facts, and dispositions through learning by doing, tutorials, mini-simulations, and so forth. Instruction is tailored to each learner's learning style, kind of intelligence (Gardner, 1983), interests, preferences, knowledge, and background based on the student's **personal characteristics inventory**. Students have great freedom to navigate through such instructional resources, including open educational resources (OERs), and are taught to use metacognition and self-direction.

Provides JIT, attainment-based instruction. PIES' **scaffolding** subfunction provides a JIT, personalized "instructional overlay" (such as simulations, tutorials, drill & practice, research tools, and student-expert academic communication tools) to support learning throughout each project. The emphasis of this subfunction is on learning by doing multiple, authentic, divergent performances (to promote transfer) for individual skills, understandings, and other kinds of attainments until mastery, with the help of tutorials and demonstrations when appropriate, similar to the Khan Academy (<https://www.khanacademy.org/>). This instructional support is sometimes provided automatically to a student when he or she reaches a certain point in the project, sometimes suggested by his or her virtual pedagogical agent or teacher when he or she reaches that point, and sometimes left to the student to request the support whenever he or she wants it. This instruction promotes efficiency of learning, student motivation, and transfer of learning to diverse contexts and develops automaticity of skills when appropriate (J. R. Anderson, 1996). Furthermore, PIES automatically collects data on student performance on each attainment and makes it available to the student and his or her advisory committee, to promote self-directed learning.

Personalizes the instruction. Different than many learning management systems that focus on content management and administrative support, PIES provides personalized instruction that is tailored to each learner's profile in terms of learning styles, multiple intelligences, goals, preferences, knowledge, and background. Using artificial intelligence techniques, such as intelligent tutoring systems, semantic webs, and adaptive systems, PIES infers, updates, and stores information about the learner from each instructional module to adapt the instructional format, content, resources, feedback, and exercises to the individual learner in subsequent instructional modules. This is a customized, localized alternative to "big data." PIES allows the learner to navigate the instruction by providing learning-path options tailored to each learner. In addition, PIES' instructional subfunctions make extensive use of aural, visual, and dynamic as well as verbal modes of instruction, thus accommodating a greater variety of learning styles and enhancing motivation. As supported by research, PIES can be seen to function as an intelligent learning management system (Yacef, 2002)—a personalized environment for learning with a greater focus on student learning styles, difficulties, and progress that allows the system to diagnose and remediate. PIES encourages personal knowledge management (Agnihotri & Troutt, 2009), with an emphasis on the learner's effort to discover, share, learn, and explore through different combinations of skills and technology. The learner can customize the appearance on the learning environment, rearrange learning content, and include or exclude learning services. Sublearning spaces can also be created to enable different types of collaboration (Ong & Nsw, 2003).

Helps students learn metacognitive skills. Researchers have found that metacognitive skills or cognitive self-regulation skills can be taught to students (Bandura, 1991; Zimmerman, 2002) and that there is a need to provide instructional strategies that inspire, motivate, and guide students to develop self-directed learning skills (Vovides, Sanchez-Alonso, Mitropoulou, & Nickmans, 2007), such as determination of learning goals, learning and management strategies, instructional resources, and external resources. PIES' virtual pedagogical agent addresses this need by providing rich resources in its instructional support for students to learn metacognitive skills, such as how to learn, monitor, evaluate, and reflect and how to become self-directed learners. Direct support is also provided to nurture students' curiosity, creativity, everyday living skills, social skills, collaboration skills, character development, critical thinking, and problem-solving skills. Of course, such support is also provided by the student's teachers and mentor.

Gives access anywhere anytime. As a web-based educational system, PIES connects students and guides across geographic and cultural boundaries for a greatly enriched learning environment. It gives students (especially those who need

special assistance) access to the instructional space anywhere anytime, so that they can learn with their teachers, personal assistants, or parents at their own pace to attain individualized learning objectives. PIES is also available across, and compatible with, various portable and wearable devices (such as laptops, smartphones, tablets, Google Glass, and smartwatches), which facilitate anywhere anytime learning to its full potential.

Integrates with OERs. PIES advocates that OERs be used whenever they can. OERs are “educational materials—textbooks, research articles, videos, assessments, simulations—that are either licensed under an open copyright license—for example, Creative Commons—or in the public domain” (Wiley, Green, & Soares, 2012, p. 2). OERs leverage on the Internet and can drastically decrease the cost of textbooks and other resources. By using OERs, PIES offers schools the option to free themselves from licensing costs and put their increasingly scarce resources to other important uses. PIES serves as a portal to various OERs, such as those of the Khan Academy, OER Commons (<https://www.oer-commons.org/>), and Mountain Heights Academy (<http://www.mountainheightsacademy.org/>). OERs are easily integrated into PIES, similar to the way apps are integrated into a smartphone, except that the OERs are seamlessly interoperable with the other apps (other parts of PIES)—they are designed to share information with them—so the appropriate OER is called up automatically when the student encounters a learning need while working on a project, and the student’s performance results are automatically fed from the OER to the student’s **personal attainments inventory**. In essence, PIES’ instructional space is seamlessly connected with educational resources that are available free or for a fee, hence enhancing students’ learning options within a social constructive learning approach, while keeping the cost low for schools.

Assessment for and of Student Learning

PIES’ fourth major function is **assessment** for and of student learning. Its sub-functions are (a) **assessing performance outcomes** in the project and (b) **assessing learning outcomes** in the instructional modules. When a group successfully completes a project or an activity, it may not necessarily indicate that each member of the group has attained all the associated learning outcomes to the desired degree of proficiency. But it is important to determine the individual learning attainments, to have learning-based student progress. Therefore, the **assessment** function assesses both *team performance* on the project and *individual student learning* in the instructional modules.

Also, PIES assesses not only academic outcomes but also nonacademic ones, such as metacognitive thinking skills; collaboration and communication skills; work ethic; and other kinds of emotional, social, and character development. In doing so, PIES enables assessment by nonteachers, including peers, community

members, and parents. Student assessment data collected through the **assessment** function automatically feed into the **recordkeeping** function of PIES.

Although we present **instruction** and **assessment** as two separate functions in PIES, they are seamlessly integrated and take place simultaneously. This is an important difference between the industrial-age and information-age paradigms. In the industrial-age paradigm, instruction and assessment take place separately. However, in the information-age paradigm, assessment is embedded in instruction. In a project, the outcomes of the project are evaluated to assess student or team performance. In the instructional modules, assessments take place within the practice exercises. A student continues with the exercises until the student meets established criteria of competency or attainment. When the student meets the criteria, he or she moves on to the next topic of instruction. The system also has identified attainments that benefit from periodic review and consequently provides periodic opportunities for each student to use those attainments in projects, as a form of review.

Assessing Integrated Performance in the Project Space

PIES' **assessment** subfunction uses projects to present authentic tasks on which the student(s) can demonstrate integrated sets of knowledge, understanding, skills, and other attainments. Simulations or virtual worlds make it easier, less expensive, or safer to do this, but some real-world performances may also be needed or desired, such as learning to back up an 18-wheel truck or do a pirouette in ballet.

After a student or team has performed an authentic task in the project, the **assessment** subfunction assists student or team reflection on the performance as a part of developing self-direction in learners. It helps students reflect on several aspects, such as the strategies they used in the project, strengths and weaknesses of student performances, and apparent misconceptions. Then, it offers feedback on the student reflections by providing formative evaluation of performances on the authentic task, when appropriate and when the performance is done in a simulation. For real-world performances, it provides criteria or a rubric for a teacher or other observer to use while observing the performance, preferably with a handheld device that uploads the evaluation results to PIES.

At the end of the project, the **assessment** subfunction assists reflection on and summative evaluation of the final product or performance in any of several ways, using the specifications in the project contract: the assessment criteria, standards of performance, and methods of assessment. Some examples of methods of assessment include hosting a contest (i.e., competition); arranging a public display (i.e., invite students, teachers, parents, and community members to attend; a rating system may or may not be used by them); and being evaluated by a single expert or a panel of experts.

The **assessment** subfunction promotes and assesses nonacademic outcomes developed while performing projects, such as metacognitive thinking, collaboration skills, and work ethic, by using self-, peer-, and expert evaluations. For self-evaluation, the system assists student reflection during and after each project. During reflection, students self-assess their own performance by reflecting on several aspects, including the strategies they used during projects, the process through which they performed, the strengths and weaknesses of student performances, and their misconceptions. The system provides different kinds of templates for different projects to help students reflect on what they have learned and the process through which they performed. For peer evaluation, their group members offer feedback on various aspects of their performance on the group project, such as collaboration and communication skills. The system provides different templates and rubrics to aid the peer assessment. And for expert evaluation, experts are invited to provide feedback on the final outcome as well as the process of their performance. The system also provides customizable templates and rubrics for this assessment.

Lastly, the final project, artifacts, evaluations, and reflections of students are stored in the system and linked to each student's inventory of attainments. Therefore, students and teachers have easy access to them for future use (e.g., creating portfolios or planning future learning activities).

Assessing Individual Learning in the Instructional Modules

Students' individual learning outcomes are assessed in the instructional modules. PIES provides functionalities, including assessing knowledge as it is being developed, adjusting difficulty to individual students, and assessing the same knowledge at different times in different ways.

Each standard is broken down into individual attainments in the **standards inventory**, and each attainment is accompanied by criteria or a rubric for evaluating mastery. PIES' instructional modules all require students to *do* things, both to promote learning by doing and to assess mastery of the attainment. When a student does not meet the criteria for a given performance, feedback (formative evaluation) is provided through hints or explanations or demonstrating the correct performance. The criteria for mastery include (a) criteria for a correct performance, (b) a criterion for number of unaided correct performances in a row, and sometimes (c) a criterion for speed of performance (or performing multiple tasks simultaneously, to ensure automatization of the skill). When the student has met all these criteria, then the summative evaluation is complete. In this manner, formative and summative assessment are embedded in the instruction—there is no test. The student has reached mastery, on which PIES updates the student's **personal attainments inventory**, including links to summary data and products, as appropriate.

When variability of a task is an issue (for near and far transfer), PIES presents the student with a representative variety of cases for the performances. The greater the variability, the larger the item pool, and the more performances the student needs to do correctly to reach mastery. Mere memorization is insufficient to perform well because the variety of cases is drawn from a large item pool. Students are required to do even more performances when automatization of a skill is important. Authentic contextual information is provided for each of the cases, when appropriate.

When the student's performance cannot be done in, and evaluated by, PIES, the system presents a rubric for a teacher or other observer to evaluate the student's performance. Typically the evaluator uses a handheld device to access PIES and enter information directly into the rubric.

When a set of related attainments (skills, understandings, memorizations, personal attributes, etc.) is mastered, a digital badge or a certificate is awarded for that set of attainments. This motivates students and provides more valuable information for potential employers and other interested individuals. For instance, when a student masters a set of collaborative skills (e.g., helping teammates, coordinating projects), he or she can be awarded a collaboration badge. Different badges can be awarded for different levels of attainment in collaboration.

In summary, PIES serves four major functions to support student learning in the information-age paradigm of education: **recordkeeping**, **planning**, **instruction**, and **assessment**. These must be seamlessly and systemically integrated with each other. In brief, the **recordkeeping** function automatically provides necessary information to the **planning** function. The **planning** function identifies **instruction** functions (mainly projects) for the student to use. The **assessment** function is fully integrated with the **instruction** function. And the **assessment** function feeds information into the **recordkeeping** function.

Secondary Functions

For PIES to be most useful for the information-age paradigm of education, these four major functions to support student learning must be seamlessly and systemically integrated with at least three additional functions: (a) communication and collaboration, (b) PIES administration, and (c) improvement of PIES. These secondary functions support users in ways less directly related to the learning process.

Communication and Collaboration

The **communication and collaboration** function plays a key role to help students, teachers, staff, parents, community members, and other stakeholders work together effectively and efficiently. First, collaborative learning in a blended or

virtual learning environment requires users to plan and use effective channels of communication (Boettcher, Conrad, & League for Innovation in the Community College (U.S.), 1999). The function suggests communication tools, such as discussion forums during project collaboration and enables users to create the contact information and maintain their contacts for further communication needs. Emails, phone calls, videoconferencing, and social networking may be identified as preferred channels of communication.

Second, with many cloud-based applications currently available (such as Google Drive and Evernote), cloud computing also contributes to effective communication and collaboration. A growing body of literature suggests that Web 2.0 technologies, which empower users by their generating and sharing content in open environments, are powerful tools for collaborative learning and communication (Augar, Raitman, & Zhou, 2004; Bonk & Zhang, 2008; Brown & Adler, 2008; Duffy & Bruns, 2006; Lamb, 2004; Lum, 2006; Williams & Jacobs, 2004). Some uses include wikis for collaborative writing, social bookmarking tools for collaborative tagging and annotation, and web content voting tools for gathering social feedback. Tools like these are used by PIES either as plug-in APIs⁴ or through links to external tools.

In this way, students are better able to collaborate with their peers and to contact teachers and seek advice without the obstacles of time and space. Similarly, parents are able to check more effectively on their children's learning progress and communicate with teachers, thus helping them be more involved in the learning process.

PIES Administration

The **administration** function involves the management of access, general student data, and personnel data. Other subfunctions could be added, such as budgeting, maintenance, and transportation, but separate computer systems are typically used for them.

Access. PIES contains an enormous amount of information, including some that is sensitive and confidential. Thus, it is crucial to have the capability to restrict access. PIES offers access to *information* based on user role and information type; it offers access to *functions* based on role and function type; and it offers the authority to *input* and *modify* information based on role and information type. For example, some teachers are able to retrieve students' general data, such as attendance records, while some school support personnel, such as a school nurse and a counselor, have access to students' medical records. School nurses are authorized to input, retrieve, and access the medical data, whereas teachers are able to access, update, and modify students' academic data but not their medical data. Considering the sensitivity of personal data, it is very important

for PIES to implement strict security while still providing appropriate access to data (Reigeluth et al., 2008).

General student data. Kinds of general student data include name, address, parent or guardian information, teachers, mentor, and school information, along with the student's attendance and current location (homeroom, learning center, or community organization), as well as health information, community activities, and major life events. Because most students will not be restricted to set rooms at set times, PIES also keeps track of the physical location of every student at school through radio-frequency identification or by the student swiping an identity card when entering and leaving any school building (or even floor or wing).

Personnel data. Kinds of school personnel data include not only general information, such as name, address, and degrees, but also data related specifically to learner-centered instruction, such as certifications, skills, and awards received, as well as professional development plans and records (Watson, Lee, & Reigeluth, 2007). These data also include a record of their assigned students and an archive of their contributions to students' learning and service on school committees. In essence, PIES not only keeps track of the school personnel's personal information but also records their instructional efforts and accomplishments over time. Some examples of these data are the instructional or assessment tools authored, evaluations performed on them, awards their students have received, and other indicators of teaching excellence (e.g., exemplary student performances). Effective management of these data by PIES will help maximize school operations.

Improvement of PIES

Finally, PIES is capable of making or suggesting improvements of itself. To better meet the learners' and all users' needs, it is indispensable to improve PIES on a continuing basis. To accomplish this, PIES evaluates and improves all its functions (major and secondary functions) and helps add additional functions or subfunctions as users need them.

The system improves through the following methods: (a) it helps users to evaluate its current functions with ratings and suggestions for improvement similar to those found on Amazon.com, to share their experiences using the resources and help other users to select resources that best meet their specific needs; (b) it self-evaluates the quality or effectiveness of its functions (e.g., the effectiveness of a tutorial based on the analysis of student data) and uses artificial intelligence to suggest improvements or at least alert the teachers, system managers, or app developers to make improvements; and (c) it helps users to request new functions.

Moreover, PIES allows users to improve or customize their individual learning portals, including the user interface, dashboard, and homepage, so that PIES better meets their individual needs, including their different ways of navigating the system.

The following are details about functions for improving the **instruction** and **assessment** functions.

Improving instruction. This subfunction supports the **development** of new instruction (projects and scaffolding) and the **evaluation and revision** of existing instruction. For **instructional development**, it helps teachers, other instructional developers, and anyone else to create new projects and instructional modules, which are much like different apps for a smartphone; only they must meet standards for interoperating with other parts of PIES. Authoring tools similar to Merrill's ID Expert (Merrill & ID2 Research Group, 1998) are the major element in this subfunction, but there is also a tool for conducting formative evaluations of the new projects and instructional modules. This subfunction helps developers identify every project with tags for the individual attainments that it encompasses, and every instructional module with tags for the individual attainment that it addresses, so as to enable linking of modules to projects.

PIES' **instructional evaluation and revision** subfunction helps teachers, students, and parents improve existing projects and instructional modules by collecting data and helping qualified individuals use those data to make improvements to existing projects and modules. It automatically collects and aggregates data (without names) for all students who work on each project and each instructional module, to identify weaknesses in them. Furthermore, students are encouraged to do a quick evaluation of each project and module, which includes Amazon-type project ratings and comments, especially suggestions for improvements. Finally, users can also attach special annotations or notes to each project and module, to identify the learning contexts or pedagogical situations for which it is suitable. These data help the original developers to improve their projects and modules, as described next, but they also help teachers, other instructional developers, and even authorized community members to improve existing projects and modules that are open to adaptation.

PIES displays the data on each project or module in a format most useful for making improvements, and it uses artificial intelligence with an instructional design theory database to recommend improvements, based on the data and user recommendations. Furthermore, it provides authoring tools to facilitate making the improvements. The subfunction allows for version control, giving the user access to all versions of the projects or modules based on conditions that are specified in the form of tags that help users to know when it may be better to use one version compared with the others.

Improving assessments. This subfunction helps teachers and others develop and improve all kinds of assessments for formative and summative evaluations of student performance and learning. This subfunction is integrated into the **instructional improvement** subfunction because instruction and assessment are developed at the same time and are inseparable. The system helps to develop criteria for mastery and rubrics, and it adds metadata to link them to the related attainment. The subfunction also enables users to link to existing instruction and assessment modules on other systems or websites and to develop accompanying elements that enhance the usefulness of those modules.

The subfunction ensures development of a sufficiently large and diverse bank of items or trials, along with metadata about the divergence and difficulty of the items. A teacher may improve or develop additional assessment items for local use by reviewing the metadata and adjusting the difficulty levels and diversity of the items. These assessments are then integrated into the instructional module or linked to the project. Then, there is a process whereby these revisions can be incorporated into the module or project by the developer, for use beyond the local area.

System Architecture

PIES is designed as a cloud-based computing system where data are accessed by the users (students, parents, teachers, administrators, and community members) through web browsers. As the schematic diagram for PIES illustrates (see Figure 1), the PIES cloud is to be housed within PIES servers. This might be supported by the U.S. Department of Education or by private foundations. Each of the major functions of PIES (**recordkeeping, planning, instruction, and assessment**) and the secondary functions (**communication and collaboration, administration, and improvement** of PIES) are to be housed in individual modules within the PIES cloud. The major and secondary functions are connected to five major databases in the PIES cloud:

1. The Standards Inventory Database, which includes federal, state, and local standards
2. Student Profiles Database, which includes personal attainments, personal characteristics, and project contracts
3. The Teammate Selection Database, which shows other students interested in the same projects at the beginning of each project period
4. The Projects Database, which contains fully developed projects, as well as ideas for projects to be developed by students
5. The Instructional Modules Database, which contains all the instructional modules, including mastery assessments in the form of practice.

In the Student Profiles Database, the **personal attainments inventory** belongs to the student, not the “school”, and can be accessed by the student at any time throughout his or her life, to promote lifelong learning and sharing of accomplishments.

In addition, the PIES cloud is interoperable and seamlessly integrated with external servers that house OERs, external web-based apps, and other open educational databases. Features of the PIES cloud include **interoperability**, **modularity**, and **customizability**.

Interoperability

“Interoperability is defined as the ability of two or more systems or elements to exchange information and to use the information that has been exchanged” (Yahia, Aubry, & Panetto, 2012, p. 444). Research in the field (Carusi & Reimer, 2010; Doove, Pronk, & van der Kuil, 2010) highlights the importance of building systems that are interoperable and easily integratable, as they offer features and functions that “. . . enjoy widespread use [and] have been extensively tested by the user community and are thus less likely to suffer from bugs and usability issues” (Jeffery & Wustemann, 2012, p. 137).

As envisioned, PIES is a platform somewhat like the Apple iOS and Android operating system (except it is in the cloud) for which anyone can create apps, as long as they meet certain standards. Unlike most iOS and Android apps, PIES apps must meet certain standards for interoperability. These include metadata conventions for linking projects to attainments, instructional modules to projects, and student data to projects and instructional modules so that the project or module can access information from the appropriate **personal characteristics inventory** and post summative assessment data to the appropriate **personal attainments inventory**. Metadata are also included for evaluating and improving the apps. Most of these apps are OERs, meaning they are free, but some are also offered for a fee, as with iOS and Android apps. It has been shown that teachers and students alike benefit when they have open, uninterrupted access to educational materials that they can use and modify to conform to their needs (Aslan & Reigeluth, 2011; Davis et al., 2010; Dutta, 2013). Some OERs don’t need to share any information with PIES, such as videos on YouTube, in which case they are typically just accessed by a PIES app through a link.

Modularity

In the field of software development, **modularity** is a key design rule that can help group a large number of components within a complex system into a “smaller number of subsystems so as to reduce the interdependency between each component” (Peng, Geng, & Lin, 2012, p. 4506). A modular design rule can not only be applied at the software development stage but also be useful when designing

Table 2. A Summary of PIES' Design Features.

Major functions	1. Recordkeeping for student learning	1.1 Standards inventory 1.2 Personal attainments inventory 1.3 Personal characteristics inventory
	2. Planning for student learning	2.1 Career and long-term learning goals 2.2 Current prospective attainments 2.3 Short-term learning goals 2.4 Projects and other activities 2.5 Teams 2.6 Supporting roles 2.7 Learning contracts
	3. Instruction for student learning	3.1 Projects: introduces, provides virtual environment, enhances real project environments, helps manage and monitor projects, affords collaboration tools, helps find, evaluate, and store resources, and helps resolve team conflicts 3.2 Scaffolding: provides JIT attainment-based instruction, personalizes the instruction, helps students learn metacognitive skills, gives access anywhere anytime, and integrates with OERs
	4. Assessment for and of student learning	4.1 Assessing integrated performances in the project space 4.2 Assessing individual learning in the instructional modules
Secondary functions		1. Communications and collaboration 2. PIES administration: general student data, personnel data 3. Improvement of PIES: improving instruction, improving assessments
Architectural features	Databases	1. Standards Inventory Database 2. Student Profiles Database 3. Teammate Selection Database 4. Projects Database 5. Instructional Modules Database
	Other features	1. Interoperability 2. Modularity 3. Customizability

Note. PIES = Personalized Integrated Educational System; OER = open educational resource; JIT = just-in-time.

the user interaction or user experience. User interaction or user experience becomes relevant when designing interfaces for web-based applications through which the modules in PIES are accessed and used by the students.

By using the modular design rule, developers of the system are able to concurrently build separate sections of the system, thus saving time and money (Gershenson, Prasad, & Zhang, 2003; Langlois, 2002; Peng et al., 2012). Because individual features of the system are built on separate modules, PIES is a much lighter and more agile system that can be easily accessed and used through simple web browsers. From the administrative point of view, **modularity** ensures an easier debugging and quality assurance process for PIES (Gershenson et al., 2003; Langlois, 2002; Peng et al., 2012).

Customizability

Customizability is defined as “the attributes of a portlet⁵ that enable it to be customized by the user, to reduce the effort required to use it and also to increase satisfaction with the portlet” (Jeong & Hong, 2012, p. 574). The web-based interface to access the functions and features of PIES is customizable. Users have the ability, by selecting and deselecting PIES functions in their portal, to display only functions and features that they wish to use, and by embedding external modules (apps).

Conclusion

In summary, PIES is a set of design specifications for a technology system to support the learner-centered paradigm of education. It has four major functions, three secondary functions, and three architectural design features, as shown in Table 2.

Fifty years of piecemeal educational reforms have left our public education systems increasingly inadequate to meet the educational needs of a postindustrial society, but there are over 140 school systems (mostly charter schools) that have transitioned to the learner-centered paradigm (Reigeluth & Karnopp, 2013). The largest positive effect on increasing the current rate of paradigm change would likely be the development of technological tools appropriate for the learner-centered paradigm. Without such tools, it is difficult for teachers to truly personalize learning and base student progress on learning rather than on time.

This article has presented a design of a system that could provide such tools, PIES. It is our hope that this article will inspire researchers to advance these design specifications and develop such a system.

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Notes

1. A mentor teacher is the student's primary teacher or advisor—someone who gets to know the student well over a period of several years.
2. Each student has only one "mentor teacher," who typically serves that role for 3 or more years. However, other people may also be mentors for a single project, including other teachers, community experts, other experts, parents, and guardians. According to Mcpartland and Nettles (1991), "[m]entoring is commonly defined as a one-to-one relationship between a caring adult and a student who needs support to achieve academic, career, social, or personal goals" (p. 568).
3. Mashup is defined by Wikipedia as "a web page, or web application, that uses content from more than one source to create a single new service displayed in a single graphical interface."
4. According to Wikipedia, an API (application programming interface) "is a set of routines, protocols, and tools for building software applications."
5. A portlet is a web-based component that processes requests and generates dynamic content. The end-user essentially sees a portlet as a separate content area that occupies a small window within a web page.

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