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DOI 10.1007/s11121-017-0842-9

Using Technology and Assessment to Personalize Instruction: Preventing Reading Problems

Carol McDonald Connor[1]

Abstract Children who fail to learn to read proficiently are at serious risk of referral to special education, grade retention, dropping out of high school, and entering the juvenile justice system. Accumulating research suggests that instruction regimes that rely on assessment to inform instruction are effective in improving the implementation of personalized instruction and, in turn, student learning. However, teachers find it difficult to interpret assessment results in a way that optimizes learning opportunities for all of the students in their classrooms. This article focuses on the use of language, decoding, and comprehension assessments to develop personalized plans of literacy instruction for students from kindergarten through third grade, and A2i technology designed to support teachers' use of assessment to guide instruction. Results of seven randomized controlled trials demonstrate that personalized literacy instruction is more effective than traditional instruction, and that sustained implementation of personalized literacy instruction first through third grade may prevent the development of serious reading problems. We found effect sizes from .2 to .4 per school year, which translates into about a 2-month advantage. These effects accumulated from first through third grade with a large effect size (d = .7) equivalent to a full grade-equivalent advantage on standardize tests of literacy. These results demonstrate the efficacy of technology-supported personalized data-driven literacy instruction to prevent serious reading difficulties. Implications for translational prevention research in education and healthcare are discussed.

✉ Carol McDonald Connor
connorcm@uci.edu

[1] University of California, Irvine, CA, USA

Keywords Reading · Writing · Literacy · Academic · Intervention · Instruction · Precision intervention · Individualized instruction

Across disciplines, from medicine to education, we are seeing an increasing understanding that industrial age models of one-size-fits all are not effective for a significant proportion of patients and students. New tools are allowing precision diagnosis and treatment in medicine, particularly with new methods, monitoring devices, and genetic testing, as elucidated in the other articles in this special issue. While personalized instruction in education has a long history (Deno et al. 2002; Lembke et al. 2010; Potts et al. 1993), the hope is that the introduction of technologies such as intelligent tutoring, online adaptive assessments, algorithms, and professional support systems will lead to more personalized instruction and better student learning outcomes. Prevention science offers an important perspective for education inasmuch as there is compelling evidence that preventing reading disabilities and academic failure is more cost effective, both socially and economically, than remediation (G. J. Duncan and Murnane 2011). One might wonder what education is doing in a special issue focused on mental health. In fact, academic achievement is highly related to mental health and important life outcomes (Connor 2016). The National Institutes of Health recognize reading disabilities as a serious public health issue, and children who fail to learn to read proficiently are at serious risk of referral to special education, grade retention, dropping out of high school, and entering the juvenile justice system (Reynolds and Ou 2004). Moreover, precision healthcare shares with education the promise of embedded algorithms and valid reliable assessments to recommend personalized recommendations that are tailored to individual needs.

In this article, I focus mostly on one particular technology, Assessment-2-Instruction (A2i), which is a teacher

Published online: 15 September 2017

professional support system. A2i was specifically designed to support kindergarten through third grade teachers' efforts to personalize (or individualize) the literacy instruction they provide. Such assessment data-informed instructional interventions have been called instructional regimes (Cohen et al. 2003) and are recognized as providing important standards of practice in contrast to the more idiosyncratic instruction observed in too many classrooms in the US. I will also briefly present the Word Knowledge e-Book (WKe-Book), which was developed specifically to improve third through fifth graders' ability to figure out the meaning of unfamiliar words (i.e., word learning strategies) and to monitor and repair their comprehension. WKe-Book development was guided by eye movement studies that showed that children with weak comprehension skills frequently fail to monitor and repair their comprehension when they encounter words they do not know. I present the WKe-Book intervention as a compelling case for the importance of both teachers and technology in personalizing instruction to promote stronger student learning.

Individual Differences and Child X Instruction Interaction Effects on Reading Outcomes

There are multiple sources of influence on children's development and learning (Bronfenbrenner and Morris 2006), and this is particularly the case with reading, which is a human invention. We have not evolved to read and write the way we have evolved over the millennium to talk. Indeed, by some estimates, writing and reading were invented only about 5000 years ago (Daniels and Bright 1996). The process of reading requires the integration of neural systems, including language centers, auditory centers, regulatory centers, and vision centers of the brain, and essentially re-wires these systems to create new neural pathways (Simos et al. 2007). Unlike language, which is experience expectant and develops even in the face of serious barriers, such as deafness and brain damage, learning to read is easily disrupted and requires explicit instruction and practice. That is, in order to learn how to read proficiently, children must be explicitly taught the alphabetic principle – that the abstract symbols we call letters represent the phonemes of our language, which can be combined to form meaningful words (NICHD National Reading Panel 2000). Moreover, this skill needs to be fluent and automatic or the cognitive effort required to decode the words will overwhelm the ability to comprehend the meaning of written texts.

Language provides the foundation for reading. When language skills are weak or underdeveloped, so is literacy skill development (Catts and Kamhi 2004). For example, children who are deaf or hard of hearing (DHH) have limited access to language unless they are exposed to native speakers of ASL early in their life. Because 90% of DHH children are born to parents with normal hearing, many DHH children have serious language delays. Not surprisingly, on average, DHH students graduate from high school reading at only a 4th grade level (Allen 1986; Holt 1994). However, with explicit instruction and the use of auditory interventions, such as hearing aids and cochlear implants, DHH children's language and reading can improve (Connor 2006; Lederberg et al. 2014).

Although it had been assumed that once children learn to decode (i.e., sound out words), comprehension will naturally follow (Rayner et al. 2001), new research shows that this is not the case. Learning to link language understanding to the text they are reading also appears to depend on explicit instruction in how to make these connections. It is possible for children to be able to decode but still be unable to understand fully what they are reading (Compton et al. 2008). Discussion about the meaning of texts and explicitly teaching comprehension strategies support children's reading comprehension gains (e.g., Connor et al. 2016; Goldman et al. 2016; Murphy et al. 2009).

To summarize, there are three principal skills associated with proficient literacy –language skills, decoding skills, and text comprehension skills – and children vary widely on these skills. For language skills, differences emerge prior to school entry (National Early Literacy Panel 2008). For decoding and text comprehension, differences begin in kindergarten and often widen as children progress through school (NICHD National Reading Panel 2000).

The Development of A2i and the Individualizing Student Instruction (ISI) Intervention

Our early investigations focused on whether the effect of literacy instruction would depend on first graders' language and decoding skills (Connor et al. 2004b). This was because fully 30% of children were not learning how to read proficiently by 4th grade and this percentage was even greater for children living in poverty. Moreover, the reading wars regarding whole language vs. phonics were raging and both sides were taking a one-size is best for all approach (Connor et al. 2004b). Using classroom observations of literacy instruction coupled with fall and spring assessment of children's reading and vocabulary, we found that the effect of instruction – code-focused or meaning focused – depended on the skills children brought to the classroom. For example, children with weak decoding skills made greater gains in classrooms where their teachers spent more time in code-focused instruction (e.g., teaching phonics and fluent sight word reading) whereas students with stronger decoding skills made weaker gains – a cross-over interaction effect. Moreover, these were largely whole language classrooms where there was little focus on teaching children how to decode text (Dahl and Freppon 1995). Instead children spent substantial amounts of time reading silently to themselves, which we called child-managed meaning-focused instruction. We found that students with weaker vocabulary skills (controlling for initial decoding skills) made smaller gains in reading when they spent more time in sustained silent reading whereas students with stronger skills made greater gains. Additionally, changes in amount (i.e., time spent) over the school year mattered. Children with weaker decoding skills demonstrated gains in reading when they experienced smaller amounts of child-managed meaning focused instruction at the beginning of the school year, with increasing amounts throughout the school year. We also found child X instruction interactions in preschool (Connor et al. 2006), in second grade (Connor et al. 2007b), and in third grade (Connor et al. 2004a). Thus, children who shared the same classroom and learning opportunities appeared to have very different responses to the same instruction.

Out of these correlational studies, we were able to develop computer algorithms that could compute the amounts of code- and meaning-focused instruction guided by the hierarchical linear models used to elucidate the child X instruction interaction effects on reading. Essentially, we set a target outcome (the Y_{ij} of the models), entered assessed fall vocabulary and reading scores, and solved for four types of literacy instruction – code-focused or meaning-focused instruction with the teacher, and code- or meaning-focused instruction where the student was alone or with peers (child managed). All evidence-based early literacy practices fall into one of these four types of instruction. Because each child has a unique constellation of language and reading skills, they are each provided a unique set of recommendations for literacy instruction. It is these algorithms that are used in the A2i technology.

These early studies were correlational studies (albeit longitudinal) so the causal implications of child X instruction interactions were unclear. Thus, we proposed to conduct a series of randomized controlled trials, which is the most efficient method of testing theories and is considered the gold standard in education (Shavelson and Towne 2002), randomly assigning use of the A2i technology in schools to personalize children's literacy instruction. We called this personalized instruction *Individualizing Student Instruction* (ISI) (Connor et al. 2007a).

A2i online technology is designed to help teachers use assessments results for each student in their classroom to plan and implement personalized face-to-face ad computer-assisted instruction in the classroom. The Theory of Change is provided in Fig. 1. Use of valid and reliable formative assessment is an essential part of any system in education, mental health, and medicine that supports personalization. The A2i algorithms require both reading and language scores to operate appropriately. The algorithm recommended amounts for each of the four types of literacy instruction are displayed in the classroom view (see Fig. 2; the new version of A2i is

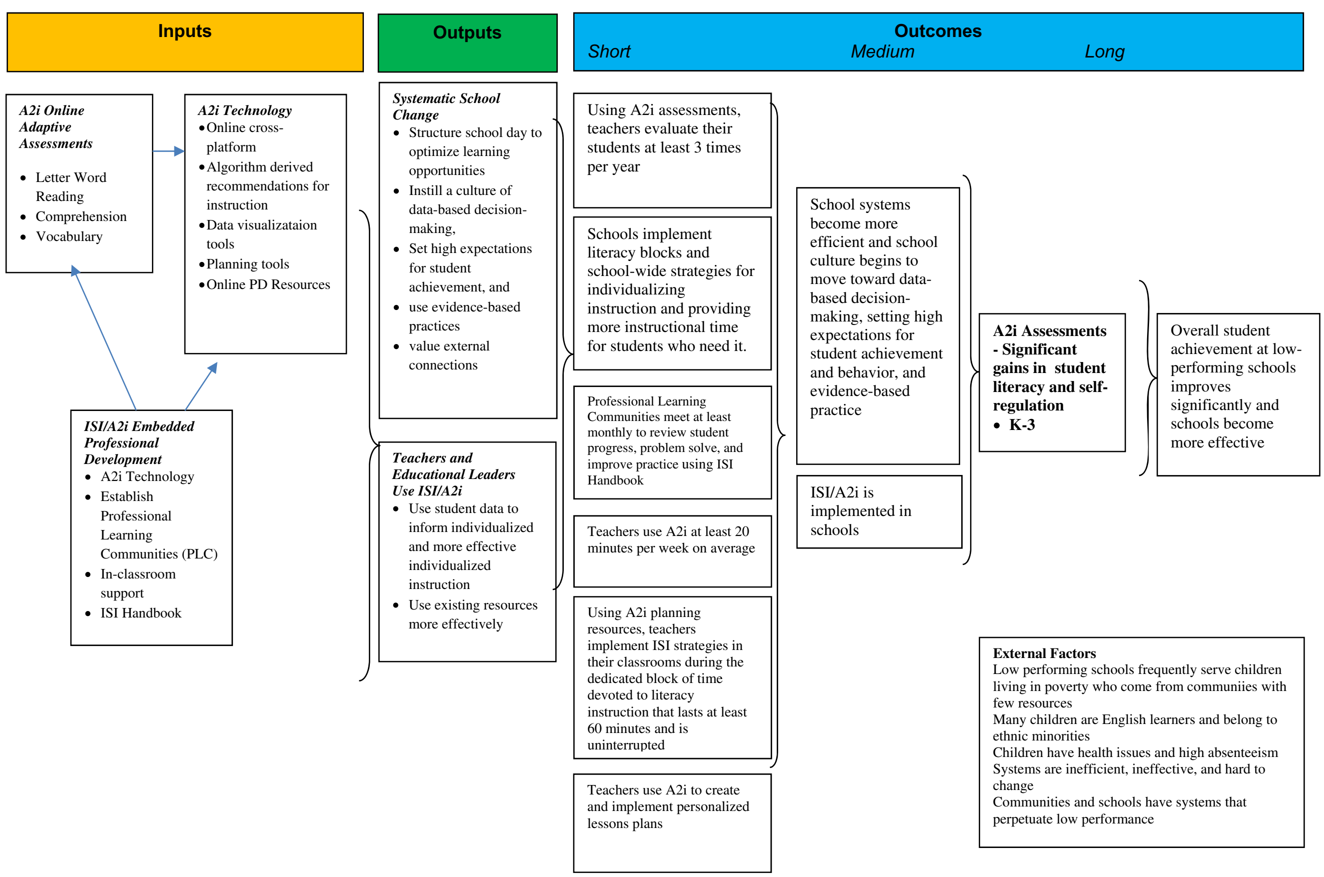


Fig. 1 A2i Theory of Change

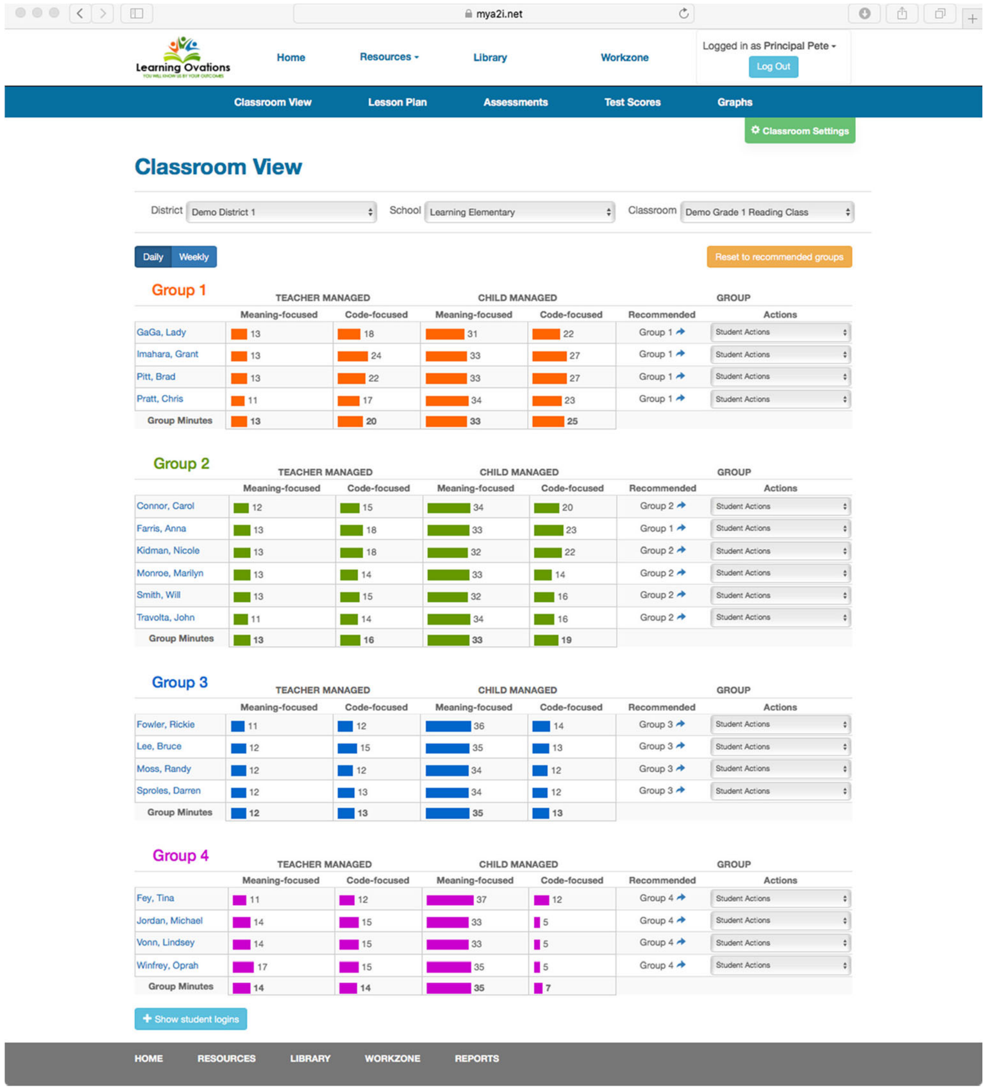


Fig. 2 The Classroom View for a first grade classroom in February. Child names are pseudonyms

depicted), which acts as a dashboard (or work zone). We also developed grouping algorithms so that children with similar reading skills were grouped together, which are also displayed in the classroom view. Teachers determined the number of groups created and could change group membership. Clicking the child's name in the classroom view, brings the user to the student information page (see Fig. 3), which shows the assessment results both graphically and in table form. There are also secure communication tools on this page. A2i was developed in collaboration with master teachers and was specifically designed as a professional support tool to empower and guide teachers' decision making, lesson planning, and implementation (Fishman et al. 2013).

For the randomized controlled trials, we used well-regarded standardized assessments, which researchers entered into A2i for the teachers (e.g., Gates MacGinitie Reading Tests). However, for the new scalable version, we developed integrated online adaptive assessments of vocabulary, decoding, encoding, and comprehension. The assessments are adaptive inasmuch as subsequent items are automatically selected based on whether children's previous responses were correct or incorrect and the difficulty level of the item. Children take these assessments independently and scores are automatically available for teachers to view in A2i (see Fig. 3). The assessments are the *Word Match Game*, which is a semantic matching task (see Fig. 4), the *Letters2Meaning* task (see Fig. 5), which includes letter and letter-sound identification, word reading, spelling, and sentence construction (students make sentences from a pool of words). Comprehension is assessed in the *Reading2Comprehension* task, which is a cloze (or maze) task requiring inferencing and comprehension monitoring. Item Response Theory (IRT) results reveal that the assessments are psychometrically strong and are highly correlated with other standardized measures of language and reading (Connor et.al 2017c).

To support the selection of appropriately challenging learning activities, A2i has lesson planning features and a library of evidence-based learning activities (see Fig. 6). The lesson

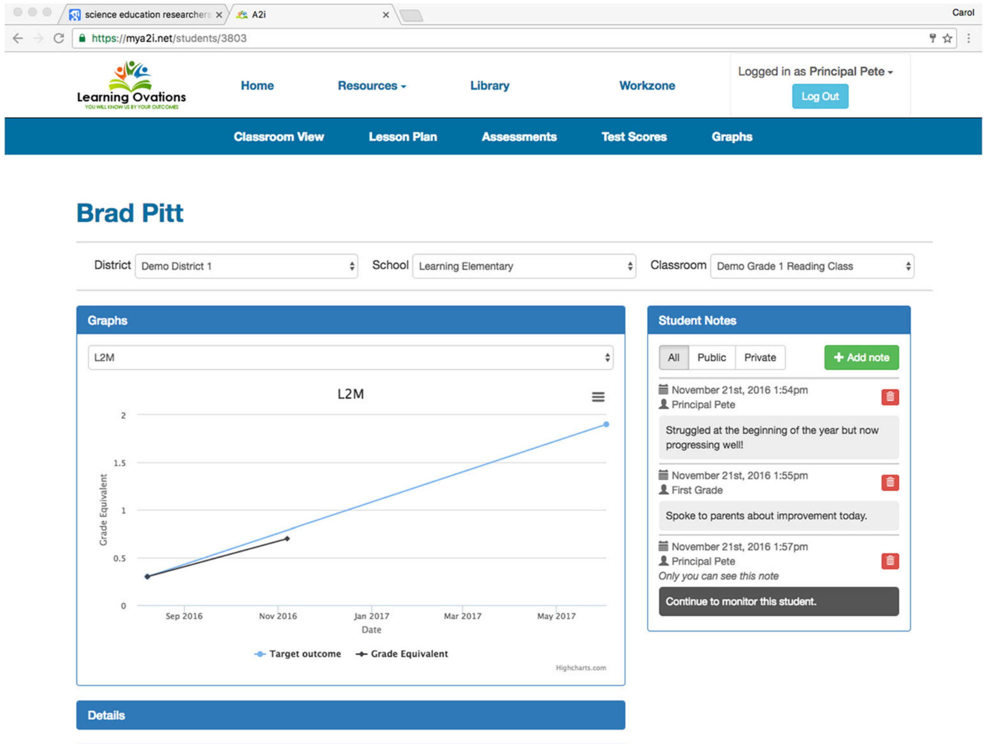


Fig. 3 Student Information Page. Child name is a pseudonym

planner will automatically select learning activities from the set of curricula and materials that: the teacher has prioritized, are at the appropriate skill level for the group, and are about the right amount of time based on the algorithm recommendations. By clicking the "view activity" button, teachers can directly download activities that do not infringe on copyrights. Teachers can select other learning activities from the A2i library using the advanced search features. As activities are completed, the teacher checks them off and the activity is recorded.

Effective professional development (PD) and improving teacher practice is an important part of the A2i/ISI instructional program and so there are integrated online PD resources available (see Fig. 7). This includes the *Handbook for Using Assessment to Guide Individualized Student Instruction in the Classroom* (Connor et al. 2015), which is designed to be used in a book club format (Gersten 2007), as well as videos of master teachers and other guides. Topics include using technology and classroom management. PD included two half day workshops, monthly communities of practice (or professional learning communities), and bi-weekly coaching during teachers' literacy block. There is good evidence that these kinds of PD opportunities are effective in changing teacher practice (e.g., Powell et al. 2010).

A2i records user-logs (i.e., click stream data) that include which pages are accessed and the length of time spent on each page. User log information is available through report features (see Fig. 8) and is presented in table graphical form. These logs can be downloaded for data analyses.

Teachers are expected to use A2i at least 20 min per week to review assessment results, plan instruction, and access the PD materials. They are also expected to personalize the literacy instruction they provide using homogeneous flexible learning groups recommended by A2i. This is typically accomplished during the 60–90 min daily block of time devoted to literacy instruction. Instruction is personalized by providing the recommended minutes/week at the appropriate skill levels for each group, which we called the *minutes and the match*. Teachers use the instructional resources with which they were already familiar, including their core literacy curriculum. Thus, they are not expected to learn to use new materials.

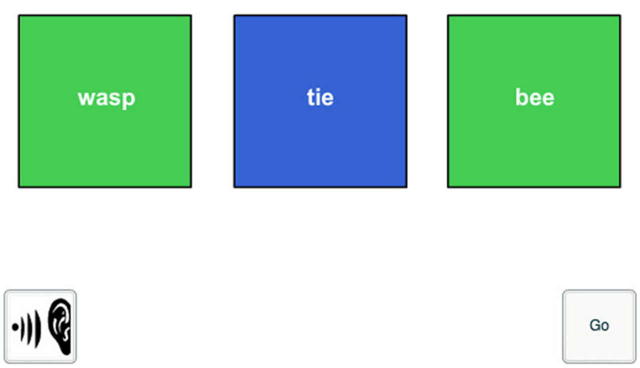
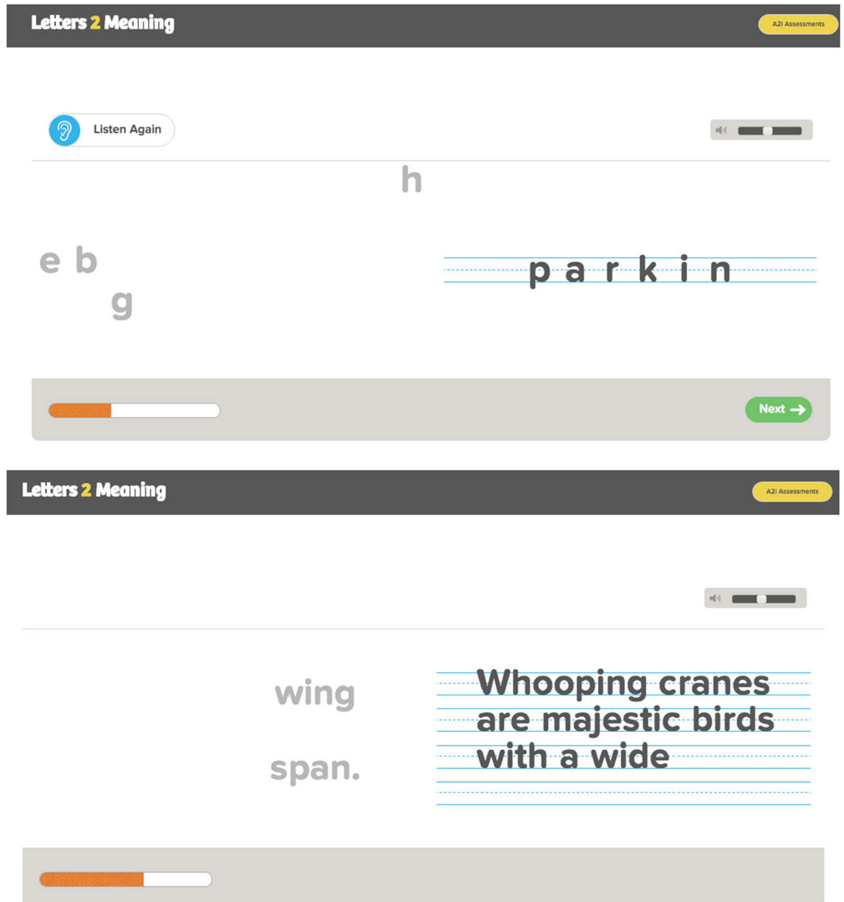


Fig. 4 Word Match Game item – child listens to the words under headphones, which flash as they are read, and then selects the two that go together. Words turn green when they are selected

Fig. 5 Two items from the Letters2Meaning (L2 M) task. The top is spelling and the bottom is sentence construction



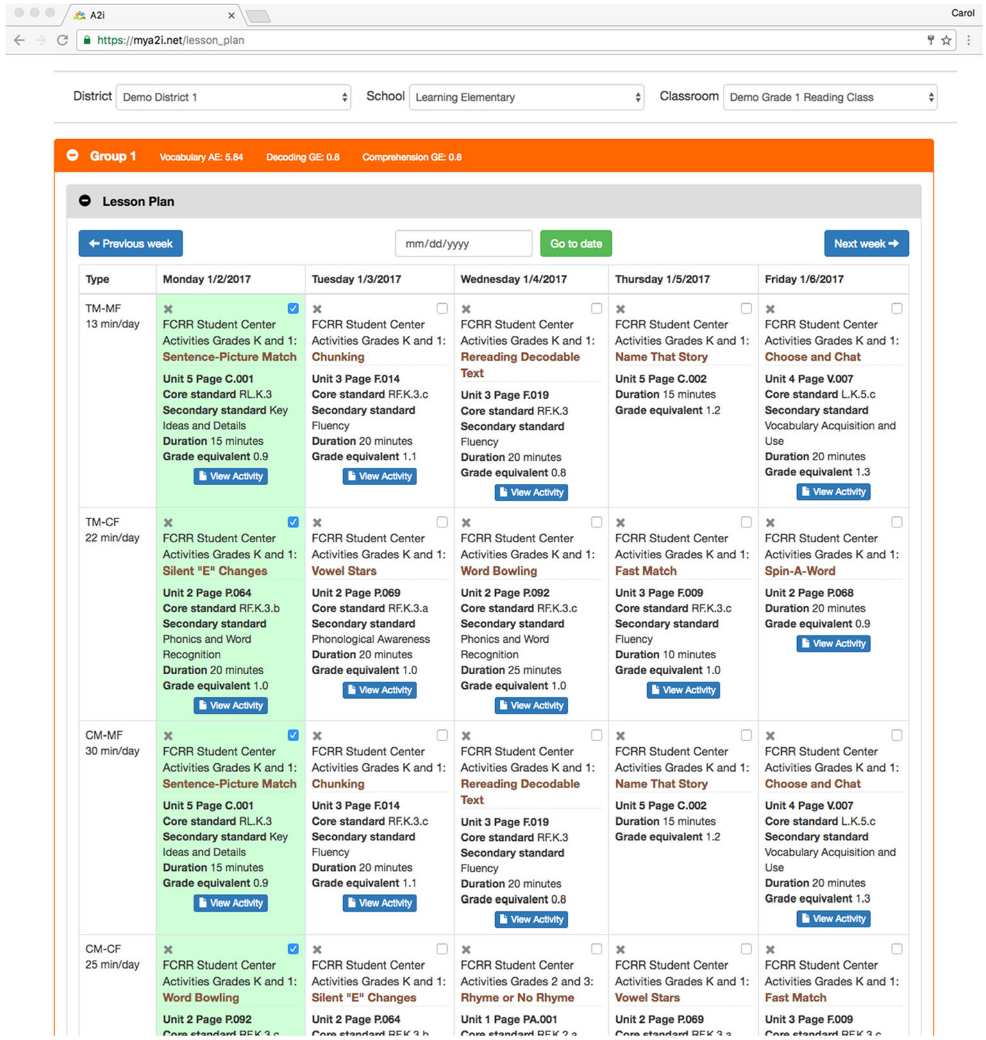
Rather, they are expected to use their instructional materials in ways that are personalized and promote achievement for all of the children in their classroom.

Procedures and Results of the Randomized Controlled Trial Research

Accumulating findings from our research conducted from 2005 on revealed that teachers were able to use A2i and implement personalized ISI instruction with sufficient fidelity that their students made greater gains on standardized assessment of reading, compared to peers in control classrooms. The results of all studies are provided in Table 1. In the first study (Connor et al. 2007a), 10 schools were randomly assigned to immediate or delayed treatment conditions with the immediate treatment group implementing ISI/A2i during the 2005–2006 school year. There were 47 teachers and 616 first graders in the study with 57% of the children in the National School Lunch Program (NSLP), a widely-used indicator of family poverty. The effect size (*d*) on a standardized measure of passage comprehension was 0.25. All of the teachers in the immediate treatment group received the previously described PD and used A2i. In the second study (Connor et al. 2011a), which replicated the previous first grade findings, 25 teachers and 369 first graders participated. Again, schools were randomly assigned to immediate or delayed treatment, approximately 45% of the children qualified for the NSLP, and 14% of the children received special education services. In this study, the effect size (*d*) on a standardized measure of word reading was 0.50. We conducted randomized controlled trials in kindergarten (Al Otaiba et al. 2011), with schools (n = 14 schools, 44 teachers, and 556 students) randomly assigned to ISI/A2i with PD or PD alone (no technology), and in third grade (Connor et al. 2011b), with teachers (n = 33 teachers, 7 schools, 448 students) randomly assigned to ISI/A2i or PD on building vocabulary skills. There was an effect size of 0.52 on a latent variable of early reading skills in kindergarten and an effect size of 0.2 on a standardized measure of reading comprehension.

Beginning in 2008, we conducted a longitudinal effectiveness trial, where we recruited first grade teachers (n = 48) and their students (n = 468), and randomly assigned them to A2i/ISI or a math intervention (Connor et al. 2013b, 2017b). We held the amount of PD constant across groups. We then followed students into second grade, recruited their teachers (n = 49) and classmates (total student n = 568), and randomly assigned teachers once again. We then followed students into

Fig. 6 Lesson Planning tools



third grade (n = 40 teachers, 541 students) and repeated the procedures. Results revealed that the effects of A2i/ISI accumulated from first through third grade. Students who participated in A2i/ISI classrooms all three years achieved, on average, a fifth grade reading level compared to a fourth grade reading level for the control group students (d = 0.77).

An important finding from this longitudinal efficacy study was that there was no inoculation effect. That is, it was not enough to get A2i/ISI in just one grade. Personalized instruction in first grade was necessary but not sufficient. Rather, sustained personalized instruction from first through third grade was required to prevent serious reading problems. Indeed, of the children who received A2i/ISI all three years, none achieved standard scores in reading of below 85 (one standard deviation below the national norm of 100) and only 6% obtained standard scores of less than 90. This is in contrast to the control group, where 22% had standard scores below 90 and several had scores below 85, suggesting serious reading difficulties.

Teaching and Technology – The WKe-Book

Many education technology and precision health care developers assume that the most effective way to personalize instruction is to rely fully on technology and take the teacher out of the picture – that learning is only personalized when it occurs using technology. For example, intelligent tutors are designed to support student learning by being adaptive and providing instruction when it is needed without teacher input (VanLehn 2011). However, the A2i/ISI protocol demonstrates that personalized instruction can be face-to-face and technology can be used to support teachers as they provide instruction. The importance of the face-to-face aspects of personalized instruction are generalizable to and may enhance precision health care. We use our study of the WKe-Book to demonstrate that teachers working with technology can be more effective that technology alone.

The WKe-Book was developed to improve third through fifth graders word knowledge and comprehension monitoring.

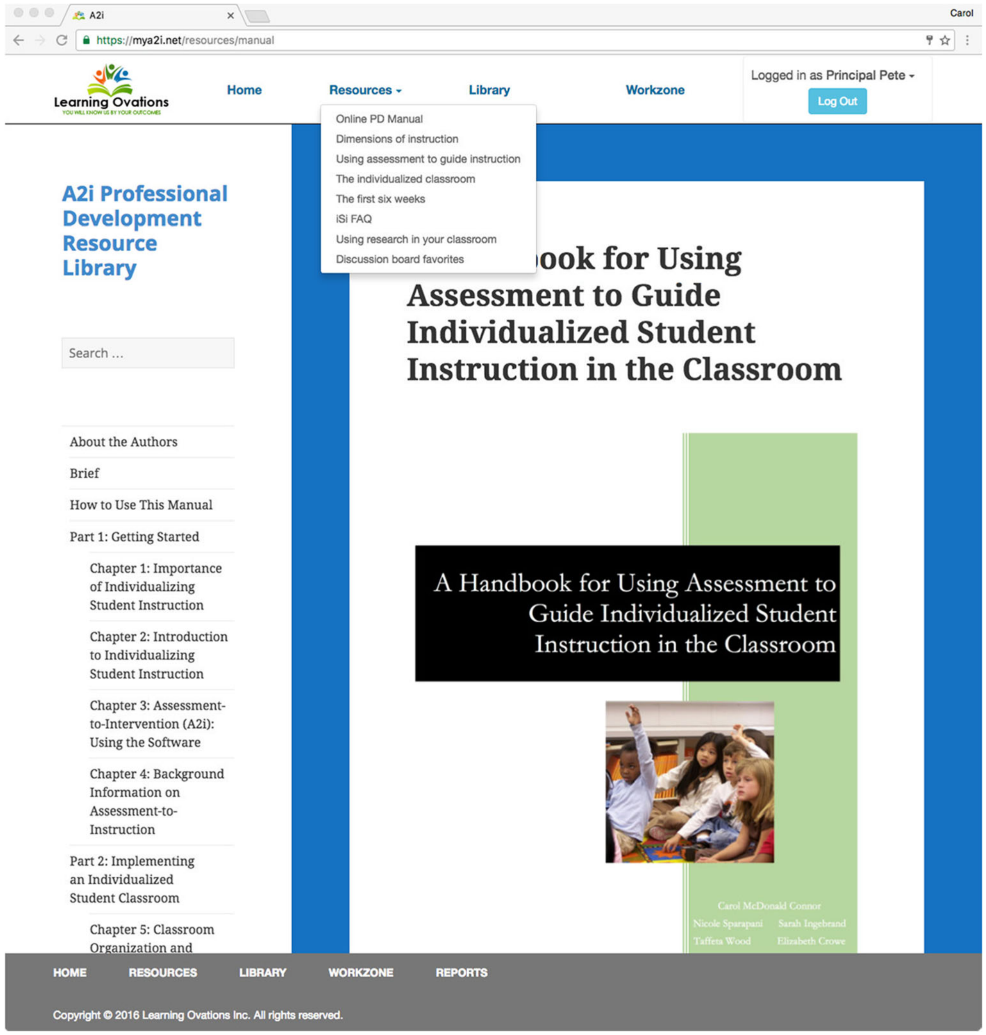


Fig. 7 Professional Development online resources

We used a choose-your-own adventure format where children controlled the plot of the story by making decisions for the main characters. For example, "Is Lakeisha intrepid or does she vacillate?" By using vocabulary words we were sure the students would not know, we forced them to employ metacognitive and word learning strategies. We also had comprehension monitoring questions with immediate feedback. For example, "What did the policeman mean when he said he was going to reconnoiter?" If the child chose the incorrect answer, they were provided the correct definition and a word learning strategy, and then told to "read the page again now that you know what reconnoiter means." Importantly, reading was self-paced and, because there were multiple story lines, more proficient readers could read the WKe-Book multiple times while their peers with weaker reading read the book only one or two times.

In the randomized controlled trial (Connor et al. 2017a), we randomly assigned third through fifth grade classrooms (n = 34 classrooms, 2 schools, and 846 students) to an immediate or delayed treatment condition and, within classrooms, randomly assigned children to a weekly 15 min book club with the teacher or to the no book club condition. Using class sets of iPads, children read the WKe-Book three times per week for three weeks (with testing before and after). Those in the book club condition met with the teacher while the other children read the WKe-Book at their seats. The student user-logs were used as dynamic assessments to group students, keeping students who were reading the same story stream together, and for identifying use of comprehension strategies and where students were using dysfunctional strategies (such as guess and check to answer comprehension questions). The logs provided a dynamic and ongoing assessment of children's status, and allowed us to tailor the book clubs for students' individual learning needs. The effect size on gains in vocabulary for children who read the WKe-Book but did not participate in the book club was (d) .22 relative to the control group, whereas the effect size of participating in the book club was .39. Thus, adding a face-to-face once-a-week book club almost doubled the treatment effect. This suggests that as we think about technology, preventing reading disabilities,

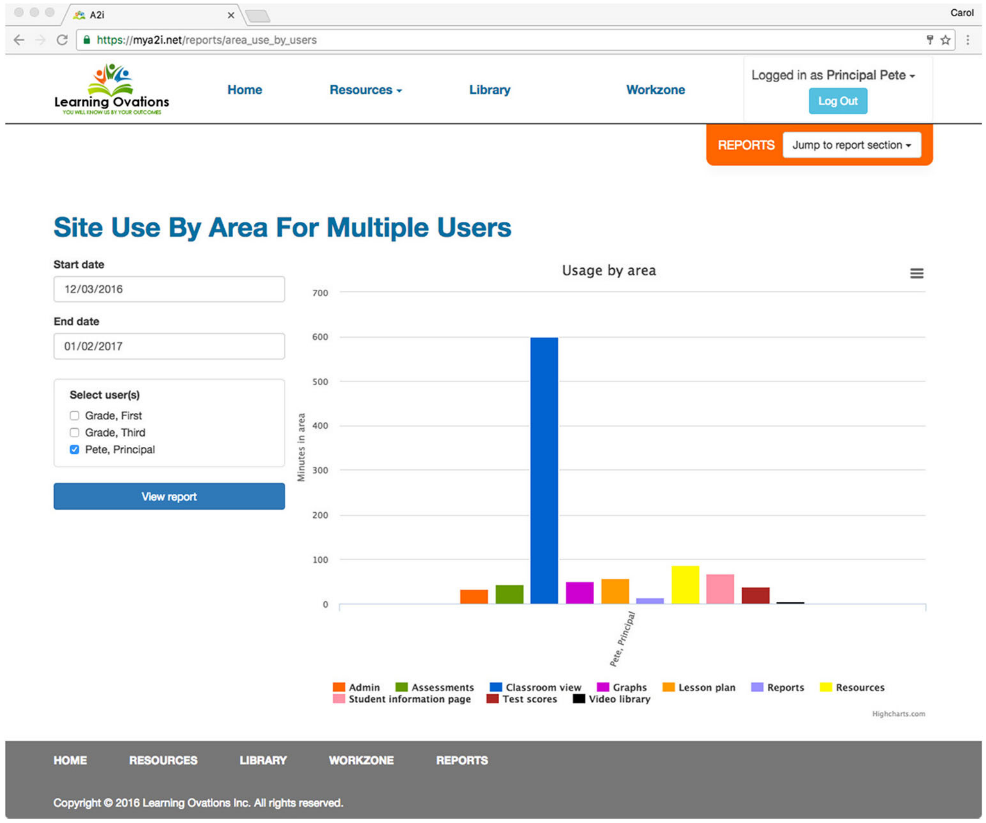


Fig. 8 User log report. Pseudonym used

promoting personalized learning, and considering precision health care, we want to use a broad definition of what we mean by technology, personalized instruction, and precision intervention across disciplines.

Discussion

The results of the ISI/A2i and the WKe-Book studies reveal that it is possible for everyday classroom teachers to become more effective in using assessment data to inform more personalized instruction, provide effective instruction, improve student outcomes, and potentially prevent reading disabilities – or at least the worst sequelae of reading disabilities. The ISI/A2i results reported here were realized within one school year (i.e., 9 months) when A2i/ISI was implemented by teachers supported by PD – but these continued benefits were not realized if personalized instruction was not provided in subsequent years. Again, participating schools served a highly diverse student body with approximately half of the students qualifying for the NSLP. In one district, almost half were African American and in the other district there was

Table 1 Summary of Randomized Controlled Trials Supporting the Efficacy of ISI/A2i

Study Citation	Study Years	Grade	% of students qualifying for the National School Lunch Program (NSLP)	Effect size (*d*) on standardized tests of letter-word reading or reading comprehension
Connor et al. 2007a	2005–2006	First Grade	57%	0.25
Connor et al. 2011a	2006–2007	First Grade	45%	0.50
Al Otaiba et al. 2011	2007–2008	Kindergarten	60%	0.52
Connor et al. 2011b	2008–2009	Third Grade	47%	0.20
Connor et al. 2013a, b	2008–2009	First Grade	39–59%	0.32
Connor et al. 2013b	2009–2010	Second Grade	39–59%	0.44
Connor et al. 2013b	2010–2011	Third Grade	39–59%	0.25
Connor et al. 2013b	2008–2011 cumulative	First-Third Grade		0.76

extensive rural poverty. In the third district, where we conducted a quasi-experiment with the new scalable version of A2i/ISI, about 70% of the children were Hispanic. We also found that the more teachers used A2i, the stronger were their students' outcomes (Fishman et al. 2013; Connor et al. 2007a). Plus, the closer the observed amounts of instruction were to the A2i recommended amounts, the stronger were students' reading skill gains (Connor et al. 2009), and the effects were large by any standard.

The purpose of this special issue is to "explore the significance, conceptual underpinnings and applications of personalized, precision healthcare, with the goal to move the concept of precision healthcare into the everyday practice of prevention science." That the issue includes educational interventions speaks to the importance of translational science. A2i and the WKe-Book have many of the characteristics considered important in technologies that support personalized precision healthcare. Professional advice is provided in the moment, as it is needed; it empowers the professionals using it; and it facilitates diagnosis and personalized treatment.

Personalized precision instruction is not widely available in schools yet although there is an increasing focus on personalized instruction and technology use in schools. For example, Education Week (Vol. 36, October 19, 2016) was dedicated to personalized learning. The dilemma is that very few of the tools mentioned in the articles have rigorous research regarding their efficacy. This means that districts may invest heavily and not see the rewards vendors and developers promise. It would be too bad to see personalized precision instruction (likewise precision healthcare) become another fad that is dismissed summarily. Rather, more research is needed on how these tools work and a better understanding of how to encourage schools to use technology and teaching practices that already have evidence of efficacy. The What Works Clearinghouse (https://ies.ed.gov/ncee/wwc/) is one tool that can be used, but more are needed. Finally, encouraging researcher-practitioner partnerships in the design and implementation of personalized learning may support districts' adoption of evidence based practices, as required by the new Every Student Succeeds Act (Duncan 2009). Along with this, tools and training to improve teachers' ability to use assessment data to inform personalized learning and promote stronger student outcomes would go far in improving outcomes for all students, including our most vulnerable students such as those attending high poverty low performing schools.

Funding These studies were funded by grants R01HD48539 and R21HD062834, and in part P50 HD052120, from the Eunice Kennedy Shriver National Institute of Child Health and Human Development; and by grants R305H04013, R305B070074, R305A130517/R305A160404, R305A170163 and R305F100027 from the U.S. Department of Education, Institute of Education Sciences. The opinions expressed are ours and do not represent views of the funding agencies.

Compliance with Ethical Standards

Conflicts of Interest Dr. Connor has an equity interest in Learning Ovations., a company that may potentially benefit from the research results. The terms of this arrangement have been reviewed and approved by the University of California, Irvine in accordance with its conflict of interest policies.

Ethical Approval All studies reported were approved by the Institutional Review Boards of the university at which the studies were conducted. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from all individual participants included in the study.

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